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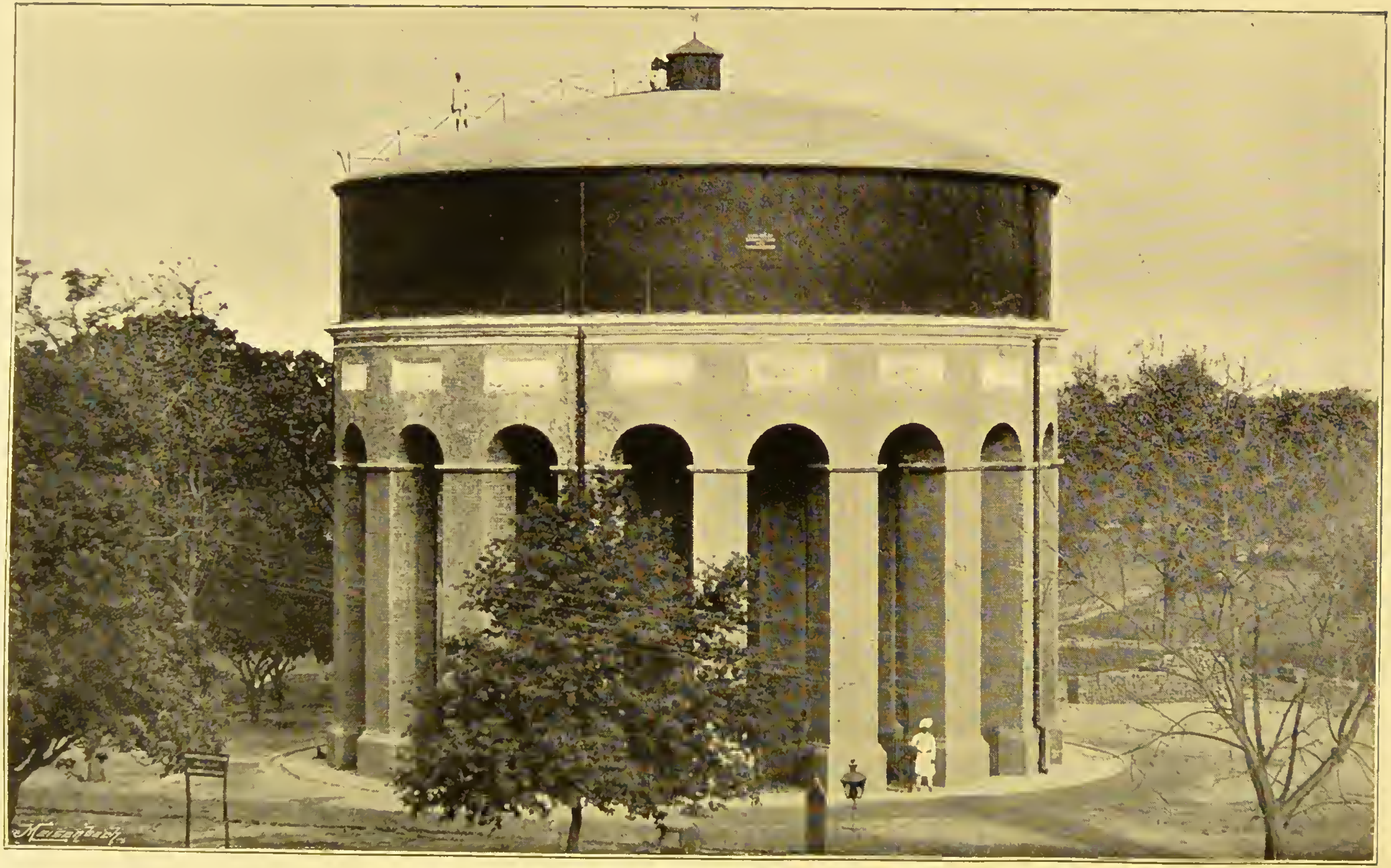

CANTONMENT RESERVOIR, ALLAHABAD. 60ft. diameter; $11\frac{1}{2}$ft. deep; height to floor 36ft. Completed January, 1892.

THE
WATER SUPPLY
OF
BARRACKS AND CANTONMENTS

BY

MAJOR G. K. SCOTT MONCRIEFF, R.E.,
ASSOC. INST. C.E.

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TO

MAJOR-GENERAL SIR JAMES BROWNE, K.C.S.I., C.B.,

ROYAL (LATE BENGAL) ENGINEERS,

FORMERLY ENGINEER-IN-CHIEF, SIND-PISHIN STATE RAILWAY,

SUBSEQUENTLY QUARTERMASTER-GENERAL IN INDIA,

AND NOW, "WARDEN OF THE MARCHES,"

AGENT TO THE GOVERNOR-GENERAL OF INDIA IN BELUCHISTAN

THIS BOOK IS RESPECTFULLY DEDICATED

BY

HIS FORMER PERSONAL ASSISTANT

AND STAFF OFFICER.

PREFACE

I HAVE endeavoured in this work to place before my brother officers the most recent ideas on a branch of Sanitary Engineering which is second to none in importance.

The work has been compiled with the view of assisting those who on the one hand may have to devise a water supply project from the very beginning, and on the other hand for those who have the minor works of maintenance and repair, and the construction of small services in connection with our barracks and military buildings all over the world. Certain portions of the book will, I hope, be useful to military foremen of works.

I have endeavoured to include in it not merely the practice that obtains in England, but also the most modern ideas from foreign countries, especially from America and Germany, where the subject has received very much attention.

There are certain matters connected with water supply which, from consideration of space, have been almost entirely omitted, such as deep-well boring, pumping machinery, the design of masonry dams, and many matters of theory. I have given references to books whence more detailed information on these special subjects can be obtained. The one chapter on theory was included at the request of some of those who attended the Senior Officers' Construction Course at the S.M.E. in 1895. Some of the methods of work, and tabular statements, in that chapter are new, and, therefore, I have stated them with a good deal of diffidence, but I believe the data to be correct, and the results to be as nearly as possible in accordance with sound principles and practice.

Further, to save space, I have given very little explanation of many of the plates. I hope that they are sufficiently clear to be self-explanatory. If it be objected that many of them are diagrams of large waterworks of a size greater than those which are ever likely to be required for military stations, I would point out that the illustration of principles is more marked in a large design than in a small one, and, therefore, large works are the more suitable for the purpose of a text-book.

It may also happen that at some of our great military stations, the concentration of troops in time of war may bring up the numbers to the population of some of the large cities from which the examples have been taken.

In a work of this kind, it is not possible to introduce much originality, and I have obtained very much of the information here given from the published works of others. I have given a list of the references at the beginning of the volume, and I have endeavoured in the text to acknowledge the source of all the information therein contained. If in any case I have not done so, the omission has been unintentional.

The text-book hitherto used at the S.M.E. has been the four lectures on Water Supply delivered in 1877 by Mr. A. R. Binnie, M.Inst.C.E., etc., formerly of the Nagpur and of the Bradford Waterworks, and now Engineer of the London County Council, whose colossal scheme for the Water Supply of London has attracted much attention recently. These lectures, which have been recognized as of the highest value both to civil and military engineers, are now out of print, and instead of reprinting them, it was considered advisable to make them the basis of part of this book, and to add to them such other matters as were necessarily, from the limited scope of the lectures, omitted in them. Mr. Binnie has very kindly permitted me to make full use of his lectures, and to reproduce the illustrations which accompanied them.

I have also to thank many other eminent civil engineers for the kind assistance which they have afforded to me in connection with this work, either by giving me practical information, or by allowing me to visit their works under construction.

To Mr. G. F. Deacon, M.Inst.C.E., formerly the engineer of the Liverpool Waterworks, my thanks are specially due for much valuable information, especially in connection with the important subject of hydraulic lime mortar. To Mr. James Gale, M.Inst.C.E., of Glasgow, Mr. James Mansergh, M.Inst.C.E., of the Birmingham Works, Mr. J. A. B. Williams, M.Inst.C.E., of Cardiff, and the many resident engineers serving under their orders, my grateful acknowledgements are due for the facilities given to me and to my brother officers for seeing their works, and for the kind and courteous reception invariably afforded to us.

From the valuable *Minutes of the Institution of Civil Engineers* I have obtained much information, and I have received permission from the Secretary, Mr. James Forrest, to reproduce several drawings.

On the very important subject of purity of water I have had the great advantage of advice from Brigade-Surgeon-Lieut.-Col. Notter, Professor of Hygiene at Netley Hospital. He has kindly looked over the proofs of the chapter in this book dealing with this subject, and has given me some useful hints.

Dr. Louis C. Parkes, M.D., has kindly presented me with the latest edition of his *Hygiene and Public Health*, from which much information has been derived.

From my brother officers in the Corps I have had much assistance. To Capt. Arthur T. Moore, R.E., my former subaltern for three years at the Curragh and Aldershot, my thanks are specially due. For the last few years he has been employed on large and important waterworks in India. He found that there was no text-book dealing with the subject, and from his own experience compiled a series of notes which he had intended to publish. When he heard that I was doing the same, he sent his notes to me with full permission to make any use of them. I have interwoven Capt. Moore's notes with my own, and trust that in so doing I have reproduced his information accurately. Owing to his being in India, it would have been inconvenient for me to communicate with him constantly on matters of detail.

Capt. E. M. Paul, R.E., has also given me much assistance, both in actual information derived from his Indian experience, and in looking through the proofs.

To Major Pitt, R.E., Aldershot, Major Courtney, late R.E., of the India Store Department, and Capt. Sankey, late R.E., my thanks are also due for assistance.

The Editor of *The Engineering Record*, an American paper which I think is not so well known among English engineers as it deserves to be, has given me much information, and has also put me in communication with various American firms, whose specialities are mentioned in the text.

In the preparation of the text I have had much assistance from all the staff of the Construction School at the S.M.E., particularly Sergt.-Major C. Lloyd, R.E., who has been specially helpful in working out tabular statements, and in many details.

I have mentioned various manufacturing firms in the text, some of whom have given me permission to reproduce illustrations from their trade catalogues, and have in many cases given me blocks of these illustrations. I hope it will be understood that in quoting these firms I do not imply that they are the only ones in the market.

Such action would be entirely contrary to Army Regulations. There are many other firms, both English and American, whose catalogues I hope will be equally studied by officers whose duty it is to carry out water-supply schemes; but it was necessary in order to illustrate the text that I should refer to some good English practice, and I considered that this necessity justified my asking some of the best-known firms for permission to quote from their publications.

Although a preface is hardly the place to introduce technical matter, more properly dealt with in the text, there is one matter which, on account of its importance, I think may be here pointed out. I allude to the necessity that exists for increased size of water mains, so as to afford efficient fire protection. In the text, I have taken the requirements of the Aldershot Fire Brigade as the basis for calculations. These requirements are less than those which are considered the least necessary by Captain Shaw, late of the London Fire Brigade. Whether they are sufficient is a point on which I cannot offer any opinion. Even with these minimum requirements, however, the sizes of the main pipes as calculated for a typical barrack for a battalion of infantry are much larger than those which are usually found in practice, both at home and abroad. In working out the sizes of pipes for the barrack shown on *Plate* LVIII., I thought I must have made some mistake, and I went over the whole ground carefully again, without finding anything wrong. A few weeks afterwards I found in certain lectures, delivered at the S.M.E. in 1878 by W. Anderson, Esq., M.Inst.C.E., etc., a statement which entirely confirmed what I had been working at, viz., that in order to maintain efficient fire service, the mains should be very much larger than they are usually constructed. The initial cost is a minor matter compared with the enormous expense sometimes caused by a fire.

I hope that my brother officers will not hesitate to point out inaccuracies or obscurities in this work. It has been written with many interruptions at odd intervals of other more pressing duty, and it is more than probable that, with all the care that one can take, mistakes have crept in. As it will form the basis of instructional work on the subject at the S.M.E., it is most desirable that such mistakes should be rectified, and that all explanations should be clear and plain even to those not naturally gifted with quick perception in engineering details.

G.K.S.M.

Chatham, December, 1895.

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LIST OF BOOKS OF REFERENCE.

(Most of which are in the Corps Library).

Title and date of publication.	Author.	Publisher.	Remarks, showing Special Subjects.
Lectures, Water Supply, Chatham (1877).	A. R. Binnie, M. Inst. C. E.	R.E. Institute, Chatham	Rainfall, Reservoirs, Domestic Fittings.
Ditto (1882)...	J. Mansergh, M. Inst. C. E.	Ditto	Prospecting, Well Sinking, Boring.
Water Supply of Towns (1893).	Professor W. K. Burton	Crosby, Lockwood, & Co.	Treatise on whole subject.
Principles of Waterworks Engineering (1894).	Tudsbery - Turner & Brightmore ...	Spon & Co.	Ditto, the theory of all structures, etc., fully treated.
Water Supply of S. Africa.	J. Crombie Brown, LL. D.	Oliver & Boyd ...	Chiefly Meteorological. Useful for Officers in S. Africa.
Die Wasserversorgung der Städte, Vol. I. (1895) (in German).	Lueger	(?) Darmstadt ...	The first volume only is published as yet. It treats of rainfall, wells, pumps, filters, reservoirs (impounding and service), and of aqueducts. Probably the best book on the subject in any language.
Treatise on Hydraulic and Water Supply Engineering (1886).	J. T. Fanning ...	Van Nostrand, New York	Very thorough treatise on all theoretical points.

Title and date of publication.	Author.	Publisher.	Remarks, showing Special Subjects.
Project de Distribution d'eau pour une ville industrielle (1888) (in French).	Vigreux	Bernard et Cie, Paris	Useful both in theory and practice for design of service reservoirs and distribution schemes.
Water Engineering (1888).	Chas. Slagg	Crosby, Lockwood	Description of English practice. Very practical treatise.
Waterworks in Cities and Towns (1882)	Hughes	Crosby, Lockwood, & Co.	Useful description of English practice and of geological formations in England.
Water and Water Supply (1878).	Professor Ansted ...	W. H. Allen & Co.	Accurate and full information regarding rainfall and drainage in the British Isles.
London Water Supply (1888).	Sir F. Bolton, revised by P. A. Scratchley.	Clowes & Sons ...	Description of London waterworks, with legal information relating to water companies, etc.
Way and Works in India (1894)	G. W. MacGeorge...	Constable	Contains narrative accounts of many Indian Schemes. A useful book to R.E. officers in India.
Masonry Construction (1894).	Professor Baker ...	Wiley & Sons... ...	Contains among other matter full information on the subject of masonry and rock fill dams.

Title and date of publication.	Author.	Publisher.	Remarks, showing Special subjects.
Design and Construction of Masonry Dams.	Wegmann	Wiley & Sons... ...	Exhaustive monograph on the theory of dams, with description of notable ones.
Hydraulic Manual (1883).	Jackson...	Crosby, Lockwood, & Co.	Working tables and explanatory text on hydraulics.
Hydraulics (1887).	Captain Love, R.E.	Madras School Book and Vernacular Society.	Ditto.
The New Formula for Mean Velocity of Discharge, by Kutter (1876).	Jackson	E. & F. N. Spon ...	Special information regarding latest hydraulic formula.
Encyclopædia Britannica article, Hydro-mechanics.	Professor Unwin ...	Black	Full information on all theoretical points.
Roorkee Hydraulic Experiments (1884).	Major Cunningham, R.E.	Thomason College, Roorkee.	Account of ten years' observations, and deductions therefrom.
Pumps and Pumping Machinery (1887).	Colyer	Spon	Pumps of all sorts.
Water Supply of Mansions.	Messrs. Merryweather & Sons		Useful treatise on small work
Well Sinking and Boring (1875).	Burnell	Crosby, Lockwood, & Co.	(Weale's Series). Practical treatise on wells.
Well Sinking and Well Boring.	Spon	Spon	Ditto.

Title and date of publication.	Author.	Publisher.	Remarks, showing Special Subjects.
The Windmill as a Prime Mover.	Wolff	Wiley & Sons... ...	American treatise on windmills.
Water or Hydraulic Motors.	Björling	Spon	On water wheels and other similar motors.
Hygiene and Public Health (1894).	Dr. Louis C. Parkes	Lewis	The purity of water fully treated according to most recent ideas.
Hygiene and Public Health (1893).	Stevenson & Murphy	Churchill	Ditto.
Parkes' Practical Hygiene.	Dr. Chaumont ...	Churchill	(Under revision at present). Text-book used by Army Medical Staff. Treats fully of purity of water, filters, etc.
Sanitary Engineering in India (1893).	Wallace	(?) Bombay	Treats of the purity of water in India, among other subjects.
Water Waste Prevention.	Meyer	Engineering Record, 92, Fleet Street.	Monograph on water waste prevention.
The Water Meter: Its Difficulties, Types, and Application.	Kent	Spon	Monograph on some water meters.
Civil Engineers' Pocket Book.	Trautwine	Wiley & Son	Invaluable pocket book on all Engineering subjects, including water supply.

Title and date of publication.	Author.	Publisher.	Remarks, showing Special Subjects.
U.S. Geological Survey, 1892-93, etc.	Various		Most useful information on sources of supply.
Minutes of Proceedings, Institution of Civil Engineers.	Various	Inst. C. E.	Subject index (published 1895) of Volumes LIX. to CXVIII., containing information on every section of the subject.
Hints to Meteorological Observers.	W. Marriott	E. Stanford	Useful guide to taking observations of rainfall, etc.
Engineering Record.	Various	"Engineering Record" Office, 92, Fleet Street.	All sections.
Proceedings of the Massachusetts State Board of Health.	Various	... ...	Exhaustive experiments on filtration.
Rural Water Supply.	Greenwell & Curry	Crosby, Lockwood	Reprint from *The Builder*, 1894. Very useful treatise

MANUFACTURERS LIST.

Speciality.	Name.	Address.	Remarks.
Air-lift Pump.	Alexander Schnee ...	Postal Telegraph Building, New York.	
Artesian Well Apparatus.	C. Isler & Co.	Bear Lane, Southwark..	
	R. Richards & Co. ..	3, Upper Ground Street, S.E.	
	Alfred Williams & Co..	39, Great Eastern Street, E.C.	
	John Spencer	Glebe Tube Works, Wednesbury.	
	Legrand & Sutcliff ...	Buntull Row, London, E.C.	
	Pierce Artesian Oil and Supply Co.	80, Beaver Street, New York.	
Ball Cocks ...	Guest and Chrimes ...	Rotherham.	
	Glenfield Company ...	Kilmarnock.	
	J. Stone & Co.	Deptford, S.E.	
	Doulton & Co.	Lambeth, S.E.	
	J. Taylor & Sons	2, Newgate Street, E.C.	
	Shanks & Co.	Barrhead, Glasgow.	
Bath Fittings.	Same as "Ball Cocks."		
Cast-Iron Tanks.	Glenfield Company ...	Kilmarnock.	
	Douglas Bros.	Globe Works, Bladon-on-Tyne.	I.G.F.'s Contract, No. 121
Cast-Iron Pipes.	Meadow Foundry Co....	Mansfield, Nottingham	I.G.F.'s Contract, No. 42.
	Glenfield Co....	Kilmarnock.	
	J. Stone & Co.	Deptford.	
	Clay Cross Co.	Clay Cross, near Chesterfield.	
	Thomas Spittle, Limited	Newport, Mon.	
	Cornell, Hiscox, and Underhill	13, Gold Street, New York.	
Cisterns (Cast Iron).	Douglas Bros.	Globe Works, Bladon-on-Tyne.	I.G.F.'s Contract, No. 121

Speciality.	Name.	Address.	Remarks.
Cisterns (Wrought Iron).	John Spencer	Globe Works, Wednesbury.	
	Braby & Co.	Ida Wharf, Deptford ...	I.G.F.'s Contract, No. 114
Cisterns (Slate)	Jones & Co.	Carnarvon	I.G.F.'s Contract, No. 158
Cocks (see Stop-cocks and Taps).			
Cotton Silicate for Lagging.	D. Anderson & Son ...	812, Old Ford Road, Bow, E.	
Filters (Chamberland-Pasteur).	Messrs. Defries & Co. ...	147, Houndsditch, London, E.C.	
Fire Engine Fittings.	J. Stone & Co.	Deptford.	
	Merryweather & Sons...	63, Longacre, W.C.	
	Guest & Chrimes	Rotherham.	
Hydraulic Rams.	J. Stone & Co.	Deptford.	
	John Blake	Accrington, Lancashire	
Hydrants ...	Merryweather & Sons...	63, Longacre, W.C.	
	J. Stone & Co.	Deptford, S.E.	I.G.F.'s Contract.
	Glenfield Co....	Kilmarnock.	
	Guest and Chrimes ...	Rotherham.	
	J. Tylor & Sons	2, Newgate Street, E.C.	
	Chapman Valve Manufacturing Co.	Indian Orchard, Massachusetts.	
	Adams & Smith	62, Gold Street, New York.	"Ludlow" hyd'ts.
Indicators for Reservoirs.	Glenfield Co....	Kilmarnock.	
Indicators for Valves.	J. Taylor & Sons	2, Newgate Street, E.C.	
	Adams & Smith	62, Gold Street, New York.	"Ludlow" valves.
	Chapman Valve Manufacturing Co.	Boston, U.S.A.	

Speciality.	Name.	Address.	Remarks.
Leathers for Rams and Pumps.	Rose, Downs & Thompson.	Old Foundry, Hull, and 1, Lall Bazaar, Calcutta.	
Meters :—			
Kennedy's Meter.	Glenfield Co....	Kilmarnock.	
Beck's Positive (Schönheyder).	Beck & Co.	150, Great Suffolk Street, Southwark.	
Tylor's Positive.	J. Tylor & Sons	2, Newgate Street, E.C.	
Tylor's Rotary.			
Tylor's Household			
Tylor's Waste Detecting.			
Tylor's Bascule.			
Deacon's Meter.	Palatine Engineering Company.	Liverpool.	
Universal Meter.	Universal Water Meter Co.	6 & 8, Eastcheap.	
Siemens ...	Guest and Chrimes ...	Rotherham.	
Venturi ...	Builders' Iron Foundry..	Providence, Rhode Island, U.S.A.	
Bee	Thomson Meter Co. ...	79, Washington Street, Brooklyn, U.S.A.	
Crown ...	National Meter Co. ...	New York, Chicago, and Boston.	
Hersey ...	Hersey Manufacturing Co.	South Boston, U.S.A.	
Pipes :—			
For Cast Iron Pipes see "Cast Iron."			
For Wro't Iron and Steel see "Tubes."			
Pipe Extractors.	Bryan, Donkin & Co. ...	55a, Southwark Park Road, S.E.	Help's patent.
Polarite ...	International Water and Sewage Purification Co.	7, Victoria Street, Westminster, S.W.	

Speciality.	Name.	Address.	Remarks.
Pumps	Tangye Bros....	Soho Works, Birmingham.	
	Gwynne & Co.	Brook Street, Holborn, E.C.	Centrifugals.
	J. A. Wade	Hull	Centrifugals.
	Pulsometer Engineering Co.	Nine Elms, London, S.W.	Pulsometers.
	W. H. Bailey & Co. ...	Albion Works, Salford..	Patent.
	Joseph Evans & Sons ...	Wolverhampton.	
	J. Cameron	Oldfield Road Ironworks, Salford.	
	John Spencer	Globe Tube Works, Wednesbury.	Small Suction Pumps.
	Fannett, Walker & Co..	Leeds.	
	J. H. Carruthers & Co.	Glasgow.	
	Drysdale & Co.	Bon Accord Works, Glasgow.	
	S. Owens & Co.	Whitefriars Street, E.C.	
	Frank Pearn & Co. ...	Manchester.	
	J. & H. Gwynne	89, Cannon Street, E.C.	
	Thwaites Bros.	Bradford.	
			N.B.—These are a few of the best known makers in Great Britain only.
Pumping Machinery.	Easton & Anderson ...	Erith	For large installations.
	Sir W. G. Armstrong, Mitchell & Co.	Newcastle-on-Tyne ...	Ditto.
	Blake and Knowles ...	117, Queen Victoria Street, E.C.	Agents for American firms.
	Worthington Pumping Engine Co.	153, Queen Victoria Street, E.C.	Ditto.
	W. H. Allen & Co. ...	Bedford.	
	G. E. Belliss	Ledsam Street, Birmingham.	
Sluices	Glenfield Co....	Kilmarnock.	
	J. Stone & Co.	Deptford.	
	J. Tylor & Sons	2, Newgate Street, E.C.	
	Chapman Valve Manufacturing Co.	Indian Orchard, Massachusetts.	

Speciality.	Name.	Address.	Remarks.
Sluices	Adams & Smith	62, Gold Street, New York.	
	Rensselaer Manufacturing Co.	Troy, New York.	
Softening Apparatus.	Mather & Platt	Salford, Manchester.	
	Thwaites Bros.	Bradford, Yorks.	
	Pulsometer Engineering Co.	Nine Elms, London.	
Stop-cocks and Valves.	Glenfield Co....	Kilmarnock.	
	J. Stone & Co.	Deptford.	
	J. Tylor & Sons	2, Newgate Street, E.C.	
	Guest & Chrimes	Rotherham.	
Surface-boxes.	Same as *Stop-cocks.*		
Tanks	Douglas Bros.	Globe Iron works, Blaydon-on-Tyne.	I.G.F.'s Contract, No. 121.
	John Bellamy	Byng Street, Millwall, E.	
	Glenfield Co....	Kilmarnock.	
Taps (Bib Valves).	Guest & Chrimes	Rotherham.	
	Comyn, Ching & Co. ...		
	Glenfield Company ...	Kilmarnock.	
	J. Stone & Co.	Deptford.	
	J. Tylor & Sons	2, Newgate Street, E.C.	
	Palatine Engineering Co.	10, Blockstock Street, Liverpool.	Lord Kelvin's Tap.
Tapping Apparatus.	J. Stone & Co.	Deptford.	
	J. Tylor & Sons	2, Newgate Street, E.C.	
	H. Mueller Manufacturing Co.	Decatur, Illinois, U.S.A.	
Tubes (Wro't Iron and Steel).	Comyn, Ching & Co....	Castle Street, Longacre, W.C.	I.G.F.'s Contract, No. 138
	Beck & Co.	130, Great Suffolk Street, London, S.E.	I.G.F.'s Contract, No. 120
	John Spencer	Globe Tube Works, Wednesbury.	
	Patent Steel Pipe Co....	Kirkcaldy, Fife.	
	Joseph Aird...	Tube Works, Great Bridge, Staffordshire	

Speciality.	Name.	Address.	Remarks.
Tubes (Wro't Iron and Steel).	John Brotherton	Imperial Tube Works, Wolverhampton.	
	Edwin Lewis & Sons ...	Wolverhampton.	
	Lloyd & Lloyd	Nile Street, Birmingham	
	John Russell & Co. ...	145, Queen Victoria Street, E.C.	
	James Russell & Co. ..	108, Southwark Street, London.	
	Cornell, Hiscox & Underhill	13, Gold Street, New York.	
Valves	Glenfield Co.	Kilmarnock	Of all sorts as shown in Ch. IX. The Manufacturers shown in this list supply most, if not all, of the different kinds, each firm having certain specialities.
	J. Stone & Co.	Deptford.	
	J. Tylor & Sons	2, Newgate Street, E.C.	
	Guest & Chrimes	Rotherham.	
	Chapman Valve Manufacturing Co.	Indian Orchard, Massachusetts.	
	Rensselaer Manufacturing Co.	Troy, New York.	
	Adams & Smith	62, Gold Street, New York.	
	Jenkins Bros.	71, John Street, New York.	
Washing Apparatus for Sand.	J. Tylor & Sons	2, Newgate Street, E.C.	Walker's Patent Sand Washer.
Well Boring Tools.	See *Artesian Well Apparatus.*		
Windmills ...	Merryweather & Sons...	63, Longacre, W.C.	
	Alfred Williams & Co...	39, Great Eastern Street, London, E.C.	

THE WATER SUPPLY OF BARRACKS AND CANTONMENTS.

CHAPTER I.

SOURCES OF SUPPLY.

General Importance.—Rainfall.—Deductions from and Tables of Observation. —Amount of Rainfall Available.—Springs.—Position of Deep, or Artesian, Wells.—Underground Reservoirs.—Special Remarks about Sites for Wells.

It is not necessary to dilate upon the importance of the subject of a pure and abundant water supply to any community. It is absolutely necessary that those to whom is committed the important duty of providing for the engineering requirements of the army of Great Britain should devote special attention to it.

The duties which devolve upon English military engineers are unique, and resemble those of no other Power. For, our empire being world wide, we are brought into contact on the one hand with all the resources and refinements of modern civilization, where labour is expensive and machinery is abundant, and on the other hand we have to go where civilization is quite unknown, where labour is easily obtained, but wholly untrained, and where the appliances of modern science are unattainable. Yet in either case, or in the many cases which occupy a position intermediate between the above extremes, the supply of a pure water to the community of troops or other bodies of our fellow-men is equally a matter of necessity. The end is the same, our duty is to acquaint ourselves thoroughly with the means, under every form and variation.

We may learn a great deal from the practice of others, not necessarily of our own nation. It does not follow that because the English have taken the lead in many engineering questions that in this important matter they can afford to neglect what has been done by other nations. There is no doubt that engineering works devoted to obtaining a good supply of fresh water have been among the first marks of civilization all over the world. If we "survey mankind from China to Peru," we find the remains all over the world of more or less ingenious expedients for obtaining and distributing water; in the first of the two countries mentioned, for instance, deep well boring has been practised for centuries, and in the other, the remains of great aqueducts, built by the Incas, still exist.

RAINFALL.

The original source of all water supply is *rain* under various forms.

From this it might be supposed that the simplest method of supplying any given building or group of buildings with water would be to collect and purify the rain falling from the clouds, instead of extracting it, as is necessary in many cases, from the earth. This method, though apparently simple, would not usually be sufficient in actual practice, because of the extent of ground which would require to be rendered so impervious to percolation, for the gathering of the water, as to produce the quantity for ordinary use. If we assume that the roof surface is equal to 60 square feet per individual (the allowance of floor space per man in English barracks), and that the net available rainfall is 30 inches, the annual amount of water collected would be 937 gallons per annum, or 2·6 gallons per day. Each man requires 20 gallons per day; hence the quantity obtained would fall far below the amount necessary. This, however, is no reason why the water falling on roofs of barracks, etc., should not be utilized and purified to the utmost extent possible. This subject will be dealt with in due course.

Another objection to the direct use of rain water is that in its pure state it is not palatable for drinking, being deficient in aeration. It is admirably adapted for washing.

Our attention has, therefore, to be directed to the rain water found in lakes, rivers and springs.

When rain has fallen, a portion of it sinks into the soil, finding its way into interstices or fissures; a portion of it may flow off in any inclination of the surface, and some may be evaporated. The relative amount of each portion will clearly vary with circumstances. If the inclination of the soil is slight, and the soil is of a porous nature, as chalk or gravel, the larger portion sinks into the soil. If, however, the inclination is steep, and the soil is impermeable, the rain flows off and tends to swell the nearest brook. Thus, in the older geological formations, we expect to find the water supply in streams and rivers, but in chalk and gravel we expect to find it by sinking wells. The portion that percolates does not all go to fill the natural underground reservoirs. A certain deduction must be made for that which is used in the nourishment of vegetable life, and in most soils, and in hot weather, evaporation will remove a much larger proportion of the actual rainfall than that which finds its way into the soil. The amount of evaporation from the surfaces of water in lakes, reservoirs, or canals, varies from 20 inches per annum in temperate to 60 inches per annum in hot countries.

The radiating power of the sun to cause evaporation, and the capacity of the atmosphere to convey the moisture so evaporated, are in reality at the basis of the whole of the problem of the source of water supply.

Oceans and seas cover four-fifths of the earth's surface, and the principal evaporation takes place in those portions of the globe where the sun's rays act in a vertical, or nearly vertical, direction, so that a very large quantity of aqueous vapour is constantly being carried into the higher regions of the atmosphere, and is being borne from the Equator to the Poles, with certain modifications due to other physical causes, the rotation of the earth on its axis, the large continents in the Northern Hemisphere, etc.

From these physical differences the rainfall varies in different places, being *nil* in the deserts of Asia, Africa and parts of America to 600 inches per annum in certain parts of India. In England it varies from 20 inches in some of the Eastern Counties to 150 or 160 inches in Cumberland.

In Western India, at Bombay, on the sea level, the rainfall is 76 inches. At Mahableshwar, on the Ghats, 114 miles from Bombay, at an elevation of 4,300 feet, it is 254 inches. At Poona, still further west, at an elevation of 1,800 feet, on the table land of the Deccan, the rainfall is only about 19 inches. The reason of the differences is that the S.W. monsoon, charged with moisture, condenses a portion of its vapour near the sea at Bombay, then meeting the mountain range of the Ghats discharges a great portion there.

arriving on the table land beyond in a comparatively dry state. Similarly the rainfall at Simla, on the S.W. slope of the great Himalayan chain, is about 60 inches, whereas at Pangi, beyond the highest peaks, and further into the heart of the mountains, there is practically no rainfall at all. Precisely the same takes place in America. In great mountain ranges the maximum rainfall is on the windward side.

In small hill ranges, such as those in the British Isles, precisely the opposite rules obtain. The circumstances of each locality render the application of hard-and-fast rules unreliable.

If, however, in any locality observations be carried out for a long series of years, an average can be obtained which will give fairly accurate results for a similar series in future. On this subject an eminent authority* has stated :—

"There is one important feature common to all places at which long and careful rainfall records have been kept; and that is that, within limits, the total annual amount does not vary much from the annual fall of a long series of years. Hence . . . we can obtain a ratio or percentage which will show at a glance what proportion the fall of any one year bears to the mean of the whole number of years. This is most easily effected by dividing the actual fall of each year by the mean amount, when it will be found that the result will either come out as unity, plus a decimal quantity, if the fall of that year is above the mean, or as a decimal quantity only if the fall of that year was below the mean" (see Tables I. to IV. at the end of this chapter).

The average of ten years is too short a period to give a reliable mean; the average of 20 years is more reliable, but, of course, the longest possible period should always be adopted.

As there is much fluctuation of rainfall, it is *not sufficient to take the longest series of records available and strike an average.*

The results of careful records made in every part of the world, and tabulated by Mr. Binnie (see Table IV. at the end of this chapter), show that :—

(1). There is a greater percentage of dry years, when the rainfall is below the average, than of wet years, when it is above the average.

(2). In 54 years out of every 100 the rainfall is 17 per cent. short of the average.

(3). In any series of years there occur occasional periods of three in succession when the rainfall falls 24 per cent. below the average; there are also longer periods of drought, varying from three to nine years, when the rainfall is 18 per cent. below the average, and occasional years when the fall is as much as 57 per cent. below the average.

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* Mr. A. R. Binnie, M.Inst.C.E.

It is, therefore, advisable to base all calculations upon the maximum possible demand, and the minimum recorded supply for a given time in the locality in question.

These facts apply to *all parts of the world;* are of the utmost importance, and show the fallacy of basing engineering operations solely on average fall.

If it is not possible to obtain a long series of observations for the actual locality in which the works are to be situated, the best thing to do is to obtain such records as are possible for that locality, and compare them with others kept at similarly situated places during the same period, where a long and continuous record has been kept. This comparison will be a fairly useful guide in determining what the mean value for the locality in question should be. Reference may also be made to isobaric and isothermal charts, published by the Royal Geographical Society.

AVAILABLE RAINFALL.

Of the total amount of rain that falls a fraction only is actually available for water supply. The general factors which modify the actual quantity are :—(1). Relative porosity of the soil. (2). Slope of the ground. (3). Nature of vegetation. (4). Dryness of the climate.

A porous soil, such as chalk, will absorb more than one which is retentive, such as clay.

Hilly ground will naturally allow surface water to pass off more rapidly than a plain, where the rain will tend to collect in pools.

Rain will be retained in ground covered with vegetation more readily than on barren soil.

Ground which is parched by a long drought will absorb more of the rain that falls on it than it would do if it were already saturated. As the ground becomes more and more permeated with moisture the flow from the surface increases. When the rainfall is scattered, *i.e.*, at irregular intervals, the relative quantity flowing from the surface is small. During any heavy continuous rain, lasting for a comparatively short time, a much larger proportion flows from the ground than would be the case if the same amount had been spread over a longer period. Similarly, if rain falls after a frost, hardly any will penetrate into the ice-bound soil, but all will flow off, causing, perhaps, heavy floods.

Hence floods are dependent not only on the actual rainfall in a given time, but also on the nature of the soil, slope of the ground, amount of vegetation, and degree of saturation of the soil. In reservoirs it is necessary to construct works to pass off the flood without affecting the stability of the structure as a whole.

In England the maximum rainfall which will produce a flood may be taken at 6 inches in 24 hours, resulting in some cases in a flood of 600 cubic feet per second per 1,000 acres.

In India as much as 23 inches in 24 hours, and 12 inches in three hours have been recorded. At the Tansa reservoir, near Bombay, a flood of over 1,000 cubic feet per second per 1,000 acres has been recorded.

In New Orleans, on the 17th June, 1895, 3·38 inches fell in 50 minutes.*

In the steep mountainous districts of India, where vegetation is comparatively scanty, the flood discharges in the rainy season are enormous. The only safe method of estimating the amount is to assume the whole gathering area to be saturated and capable of discharging the heaviest known rainfall within an hour or two of the fall. Some information (to be relied upon with caution, however), may be obtained from old flood levels.

The following remarks, taken from *Hints to Meteorological Observers*, by W. Marriott (E. Stanford, London, 1892, price 1s., a very useful book for prospecting and obtaining statistics), are of value in considering the subject of available rainfall. After detailing how to use and record rainfall from rain-gauges, the author states:—"If practicable, an attempt should be made to determine the amount of evaporation. For this purpose it is desirable to have a galvanized iron tank about 4 feet square and 2 feet deep. This should be sunk in the ground, and kept filled with water to within 3 inches or 4 inches of the top. The height of the water should be measured every day, when the difference will give the amount of evaporation. When rain has fallen, the amount as shown in the rain-gauge should be deducted from the height of water in the tank.

"The amount of water percolating into the ground may be ascertained by means of a water-tight tank filled with the earth of the locality. A convenient form of percolation gauge is one made of slate, and of a cubic yard in capacity, the upper edges being bevelled so as to have the sharp edge inside the gauge. The top of the gauge should stand about 2 inches above the surface of the ground, and the gauge should be filled with earth to within 2 inches of the top. In some cases the ordinary turf of the district is laid on the materials composing the percolation gauge. . . . The water may be collected from the gauge by means of a drain or pipe from the bottom. . . . The quantity of water percolating can be measured in a graduated glass similar in principle to, but of larger capacity than a rain-gauge glass. When very small quantities of water are required to be measured, and the gauge being one yard square, if the quantity is measured in an 8-inch rain-gauge glass and divided by 26, it will give the quantity passing through the percolation gauge."

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* *Engineering Record*, 27th July, 1895.

Measurements of existing wells also afford very useful information. "In making such observations it is desirable to select a well, and measure from a fixed point at the mouth of the well to the water surface. . . . Such measurements should not be taken less frequently than once a week, but in critical periods of the state of the water, usually in the autumn, when the water begins to rise after a period of heavy rain, more frequent observations should be made in order to determine the exact period when the water begins to rise. In selecting a well for observation, the more distant it is from a stream the better, as the underground water escaping into an adjoining stream so influences the level of water in such a well that the annual amount of fluctuation may be very small."

The following facts (mentioned in *The Builder*, July, 1894) point to the necessity of a series of observations being necessary in dealing with surface wells, and to the unreliable nature of information obtained locally :—

"In a recent survey for a village water supply three apparently deep-seated springs of most excellent quality were found in close proximity to each other. These springs were gauged on the 21st March, 1893, and yielded a total volume of 820 gallons per minute. On April 8th they had fallen to 436 gallons per minute, and on May 6th to 207 gallons. In June they were dry. In the course of the same survey a spring was brought under notice, as to the permanency of which opinions were somewhat conflicting. Reference was made to the oldest inhabitants, three nonogenarian labourers, who stated that they had known the spring all their lives, and that it had never yielded less than a certain flow. This was in February, 1893, and shortly after the spring failed."

The yield of water from a well can be ascertained by pumping down to a certain level, and observing the length of time required for the water to regain its original level.

SPRINGS.

Of the water which passes into the soil, a considerable portion not unfrequently re-appears on the surface in the form of *springs.* The water sinks through porous strata until it reaches—as it usually does at a greater or less depth—an impermeable stratum. Here it is upheld, forming an underground reservoir, the natural outlets of which are *springs,* which occur where the impermeable stratum "crops out" on the earth's surface. Such springs are sometimes classified as "land" springs and "main" springs.

Land springs are of limited capacity, the water in them being formed in superficial beds of sand or gravel overlying a stratum of clay, often ceasing to discharge when rainfall is delayed.

Main springs are deep seated outlets of underground reservoirs issuing from geological formations, such as chalk, oolite and sandstone, fed by rain, often at great distances from the spring.

As a rule (which is, however, by no means an invariable one), springs afford excellent water for drinking purposes, so that the supply from such natural fountains has become a synonym for all that is fresh, pure and limpid. The water in sinking through the soil absorbs carbonic acid from the ground air, and then becomes capable of dissolving some of the mineral constituents of the rocks over which it passes. Thus calcium carbonates and calcium sulphates are found in water issuing from chalk, oolite limestone, and sandstone ; magnesium carbonates from magnesian limestones ; iron from greensands and new red sandstone; and salts of sodium or potassium from sandstone rocks and other strata. As a rule, the temperature is constant at all times, the aeration is good, and the salts in solution are sufficient to render it palatable. The supply, however, in ordinary springs is not generally more than would suffice for small communities.

To guard against the pollution of springs, it is desirable that the ground near the point of delivery should be walled in, and the water conducted to the surface by a pipe.

The yield may be estimated by seeing how long it takes to fill a vessel of known capacity.

POSITIONS FOR WELLS.

It is, however, evident that by the properly directed operations of the well-sinker the underground reservoirs, whose natural outlets are springs, can be tapped, and the water made available for use.

The following are some simple rules for ascertaining a good site for a well necessary to tap an underground reservoir:—

(1). Look where the grass is green or brighter in one place than another.

(2). In summer insects hover over damp spots, and remain in columns above the site of springs.

(3). More dense vapours rise from those portions of the surface below which springs exist, especially in the early morning or in the evening.

(4). Springs are often to be found at the junction of valleys, especially at the junction of a long transverse valley with a principal one.

The above, however, only apply generally to surface wells, they are not sufficient nor applicable always in the case of deep wells, for which geological knowledge is necessary.

The following extract from the 13th Annual Report of the U.S. Geological Survey (J. W. Powell, Director) for 1892–93 gives important information regarding subterranean sources of water supply:—"The water obtained from rocks beneath the general surface of the country, though relatively small in amount when compared with that from streams, has great importance from the fact that dependence must necessarily be placed upon this in many localities where running water cannot be had. . . . The total number of artesian wells in the western part of the United States in 1890 was 8,097, as ascertained by the census of that year. . . . No statistics have been obtained concerning the ordinary wells, from which water is pumped or drawn by various means, but there is found in nearly every locality water saturating porous rocks near the surface in all places except on desert areas. On the Great Plains, for example, in Western Nebraska and Kansas, it is sometimes necessary to go to depths of from 100 to 300 feet or more before water-bearing strata are reached, but throughout the arid regions, as a rule, wells are successfully dug to a less depth. The widespread occurrence of water in pervious layers of the earth's crust, and sometimes in such quantities as to appear almost inexhaustible, has given rise to the notion that it flows in great channels very much as do the rivers of the surface, but covered from sight by rocks and soils. There are a few instances where underground watercourses actually occur, but these are extremely rare, and are extraordinary in their nature, being found only in great limestone deposits, or among the lava flows of recently extinct volcanic regions.

"In a majority of cases sub-surface water occurs merely as moisture saturating the rocks. If these are unconsolidated and porous, the quantity of water contained in the interstices is in the aggregate very large, while in the case of the hard compact granites or slate the proportion is extremely small. That all rocks which form the crust of the earth contain a certain amount of water can usually be shown by drying any of them and noting the loss by weight. The sands and gravels washed down from adjacent heights and filling depressions are particularly well adapted to hold moisture, and it is from these, as is well known, that the greatest quantities of water are obtained.

"The behaviour of the waters in these sands is still a matter of inquiry, and is not clearly understood. For instance, one leading question is :—Are these stationary, or do they flow freely from place to place ? It is probable that to a certain degree both of these conditions are found in nature. In a small valley entirely enclosed, the water accumulates in the sands until they are saturated, and the moisture approaching the surface of the soil begins to be evaporated.

"The matter then adjusts itself until a balance is reached between the amount which flows in and that which is evaporated, the level of the water rising until the loss is equal to the inflow. If a well be made in this sand basin and the water drawn upon, the level of the moisture in the immediate vicinity of the well is immediately lowered. The influence extends only with great slowness towards the edge of the basin, however, the water level not as a whole falling at once, as would be the case in drawing from a large open body, the place of the water removed being slowly occupied by a gradual progression of moisture from the sides. Instead of a small basin, if one of indefinite size be considered, there is seen a condition of things similar to that which takes place in a broad extent of country. The moisture at the lower limit of a large plain, escaping either in springs or by evaporation, is gradually replaced by the slowly progressing water, which percolates with a rate varying with the fineness of the rock or sand layer. The amount of water which can be taken from underground sources is limited not so much by the total quantity in the area as by the rate at which it can flow through these sands or gravels."

This information is not only of general importance, but is specially so in connection with the many arid tracts on the N.W. frontier of India.

In Afghanistan and Persia, where valleys of irregular contour occur between barren mountain ranges, the natives utilize the subterranean water for irrigation purposes by sinking a series of wells, generally across the valleys, connecting the same at the water level by almost horizontal galleries leading to the natural surface of the ground where irregularities of contour permit. Such a system of wells is called a *Karez* (see *Fig.* 1), and the advantages of it are that the length of the horizontal gallery, tapping as it does a greater portion of the water-bearing stratum than a single shaft would do, stimulates the flow throughout that stratum, and the water is protected during its passage underground from evaporation.

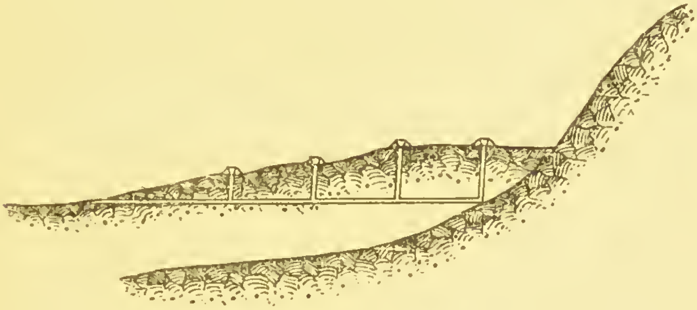

Fig. 1.

Collecting Area of Wells.

The subject of the collecting area, or cone of collection, of different surface wells is a very intricate one, and no satisfactory practical rules can be given. An approximate rule sometimes given is that in porous strata the diameter of the base of the inverted cone is about twice the depth of the well. Dr. Louis Parkes has stated in his *Hygiene and Public Health* that the distance within which a well draws water to itself is—(1), in fine sands and gravels, 15 to 39 times the depression of level produced by pumping; (2), in chalk, 57 times the depression; in coarse gravel, 68 to 160 times; and (4) in new red sandstone, 143 times the depression. These results are founded on observations. The subject is further treated in detail in Herr Lueger's *Wasserversorgung der Städte*, but the question obviously depends on the nature of the soil, the slope of the strata, and the degree of saturation, elements which cannot be usually determined with any degree of accuracy. The variations at sites near one another, and apparently under the same conditions, are very remarkable. Thus at Rawal Pindi two wells were dug to more than 80 feet below the surface without getting water, another was started at 150 yards distance from the first, and water was found at 20 feet in such quantities that it could not be exhausted. In another case a well was dug 130 feet without reaching water, but one morning the workmen, going to resume work, found 70 feet of water. In a third case a well was dug, finding water at 70 feet, but, as it fell in, another was dug 20 yards off, and water was found at 57 feet. One day this ceased, and the well was increased to 95 feet without finding water. Accurate geological knowledge of the site will assist, but absolute certain knowledge of the result is hardly to be expected in any given case.

Deep or Artesian Wells.

All strata which we have to deal with may be divided into *permeable* and *impermeable*, the former consisting of chalk, gravel, or sands, through which the water will filter, or rocks broken up by fissures along which the water passes readily. The impermeable strata are either formed of layers of dense clays and marls, or close-grained compact rocks.

Now if all the strata on a given surface were *horizontal*, the water would sink through the permeable till it reached the impermeable, upon which it would be borne up, and would ooze out at any outcrop caused by inequalities of the surface, *e.g.*, on a hill side.

If the strata were *saucer-shaped*, or synclinal, a reservoir would be formed, which would in course of time become filled, and would overflow after heavy rain. If the basin be filled with permeable material only, the water might rise to the surface of the ground anywhere. But if the permeable material were again covered with impermeable, so as to have a ring of the former only exposed, the water would rise to the surface only on the area of the ring itself, and if a well be dug in this super-stratum until the water-bearing stratum were tapped, we should find the water rising up the well towards the surface of the ground, forming what is known as an *artesian* well.

As a matter of actual fact, however, the surface of the earth is so irregular that the existence of a perfect basin, such as we have assumed, is most rare. In most of the impervious strata there are cracks and "faults;" there are certain planes of bedding and joints, all of which points affect the question, and are o great importance.

It is obvious that a geological knowledge of the site is a matter of first importance.

As an illustration we may take (*Plate* I.) a section of a typical basin.* The water in all the strata, shown in the section, is derived from the rain which falls on those portions of their surface that are not covered by the London clay, and is upheld by clay beds of the gault. Thus it accumulates in the strata up to the horizontal line AB, at which it overflows by springs in valleys, *e.g.*, at C. Below this line all the chalk, etc., is filled with a permanent reservoir of water, except when faults or fissures allow it to escape into lower strata. Except where such escape occurs, the level of AB gives the line up to which water will rise in any well by hydrostatic pressure, when the superincumbent London clay is perforated. If the perforation be below the line AB as at GH, the water will rise in a perpetually flowing *artesian* fountain.

Wells thus sunk through an impermeable to a permeable stratum are known as *deep* wells in contradistinction to *shallow* wells, which are merely sunk into superficial porous beds overlying an impermeable stratum. The construction and position of both kinds of wells will be considered more fully in a later chapter. *Artesian* wells are deep wells of the nature above alluded to, where the surface of the ground is below the level of the water in the subterranean reservoir, and hence the water rises to the surface in the well without any pumping.

Faults in geological strata affect this question in various ways. The section in *Fig.* 2 represents a portion of a basin intersected by a fault HL filled with clay. A, B, C, D are porous strata, the remaining ground being impervious. It is quite clear that not only the rain water which enters the out-crop at A, B, C, D of the inclined and porous strata, but also all that falls on the surface of the impervious strata between each, will be held up by the fault. The rainfall on CD will flow down C, that between C and B will flow down B, and so on. A well sunk at E will yield water which will rise to a greater height and in greater volume as each successive layer is tapped.

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* This corresponds very nearly to the section of the earth at Paris. The same general effect is produced near London, but the basin there is not so synclinal as that shown, and is much interrupted.

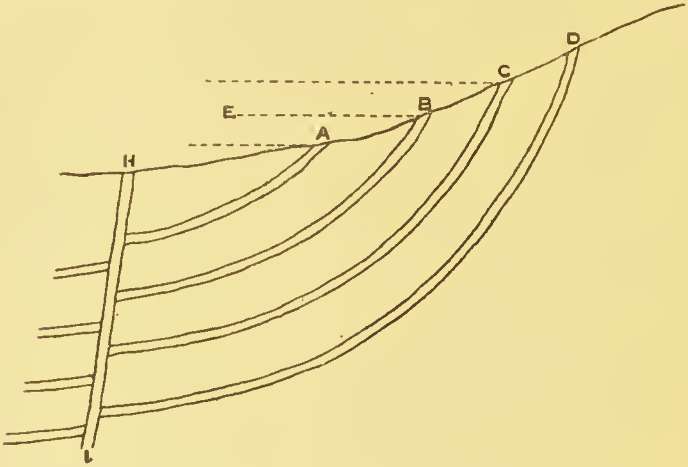

Fig. 2.

In many limestone districts the faults become filled with clay, which acts as a dam, and forces the water out at the surface.

The springs thus formed have frequently led to the discovery of the geological faults.

On the other hand, faults may act as conduits, leading water down through impervious strata to others below.

As a general rule, the level of water in the underground reservoirs does not remain a constant, nor does it remain absolutely the same for all parts of the same stratum. If there is an outfall or spring the level of saturation is inclined towards that spring; and in every case the level varies with the season of the year and the rainfall, being least in October or November, and greatest in February or March in England.

The rule as to the level of the water line not being a constant is not invariable, however, for Professor Boyd Dawkins states:—

"In England, in the chalk, a well marked water-line or surface is always to be found, *e.g.*, near the shore at Brighton, it is at the sea level, and it gradually rises in the chalk as we go towards London. Some miles north of London it reaches its maximum height of 400 feet above sea level. The position of these water-lines is of much importance to waterworks engineers. . . . So great is the natural reservoir in the chalk that the whole of London water is taken from it without causing any perceptible alteration in the level of the surface. The local effect, however, is extremely marked, and shows how slowly the water runs through the chalk and how steep the inclination of the water surface must be. Seasons of the year, droughts and floods alike, have very little influence on the water level. Rivers in the chalk districts exist only on conditions that their level is the same as the water level in the rocks through which they pass. Places supplied from these vast reservoirs need never fear a water famine."

It has been estimated that it takes from four to six months for water to filter through 200 feet to 300 feet of chalk.

On the other hand, the surface drainage materially affects the level of the surface wells. This was markedly proved at Lucknow, where an extensive scheme of surface draining of the cantonments was carried out in 1877–81. The water supply obtained from surface wells was very sensibly diminished, the water level in the wells being everywhere reduced.

The typical conditions* for a constant water supply by means of wells are as shown in *Plate* I., *i.e.*, where there is a broad extent of pervious strata overlying a band of impervious formation on *synclinal*, *i.e.*, saucer-shaped axis. The difficulties that practically present themselves are :—(1). To know whether the proposed site is on a synclinal or anticlinal axis. (2). To know whether any impervious band of clay underlies the permeable strata.

As regards the first of these two points, observations may be made of the sections of the earth's surface in quarries, cuttings, river escarpments, etc. Any fossils which may be collected will furnish a means of identification as to the strata, reference being made to any geological museums for comparison. In observing the dip of strata, it will often be found that the strata do not follow the inclination of the ground surface. Frequently synclinal axes are found at the tops of hills and anticlinal axes in valleys, due to the denudation of strata, already strained by upheaval. Hence it does not follow that the best site for a deep well is in a valley. If the synclinal axes happened to correspond with the valley it would, of course, be the most economical place to bore for water.

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* From notes of lectures by Professor Lydekker.

In all cases where boring for water is carried out, endeavour should be made to find out where the out-crop of the water-bearing stratum is situated, so as to determine its thickness. The out-crop of other overlying strata should also be ascertained.

As regards the other difficulty, viz., the existence of impervious sub-strata, it may be generally stated that where oak trees flourish, and where the country is flat, there clay is the chief ingredient of the soil. In the Weald of Kent, for instance, oak trees are abundant in the flat plain of clay, but they do not grow in the overlying chalk formation. Where pines grow, as at Aldershot, Chobham, and Woking, they are characteristic of sandy soil.

Gravel is generally a good water bearer, and in a gravelly valley with a river flowing down, water may generally be obtained in shallow wells in any part, by percolation from the river. Frequently in dry valleys water may be obtained by digging into the gravel which forms the bottom.

In deep wells sometimes boring is carried out through an impervious stratum into a porous one below, so that instead of the yield being increased, it is lost altogether. This danger must be guarded against by obtaining the best knowledge possible of the geological conditions of the site.

TABLE I.

Table showing Rainfall in each Year during the fifty-two years, 1830—1881, *at various places in England.*

Years.	Chil-grove.	Nash Mills.	Oxford.	Exeter.	Orleton.	Pode Hole.	Boston.	Bolton.	Kendal.
1830	*35·80*	*27·90*	25·31	27·42	*29·10*	34·29	25·90	*55·30*	58·03
1	*40·00*	*31·40*	27·48	30·78	27·58	34·32	25·57	62·30	61·42
2	*28·90*	*25·20*	24·32	26·76	26·50	28·87	22·55	53·77	49·69
3	*34·00*	*27·30*	21·50	30·62	29·44	24·95	22·62	51·70	55·42
4	32·85	21·70	19·91	22·34	28·84	18·10	14·66	43·98	65·14
5	30·97	27·59	23·80	28·20	27·27	24·20	21·87	46·44	55·89
6	41·00	31·00	22·13	30·50	28·16	26·65	21·38	53·78	64·33
7	27·01	21·10	19·35	23·70	28·55	23·90	23·58	42·25	48·39
8	30·60	23·13	21·18	33·04	26·36	21·10	18·95	47·85	45·74
9	40·50	31·28	30·63	35·84	34·15	31·65	28·48	45·26	57·97
1840	28·90	21·44	18·42	22·76	25·80	21·30	18·61	45·03	48·21
1	43·35	32·10	31·26	36·46	32·77	29·45	27·26	53·87	53·85
2	29·80	26·43	21·64	27·70	25·48	32·10	24·73	38·63	48·08
3	34·61	26·47	24·20	33·24	29·94	29·45	24·29	49·40	56·31
4	28·26	23·57	17·80	23·79	21·73	22·20	21·64	34·63	43·01
5	30·68	24·53	21·41	25·34	27·41	27·25	25·29	48·11	53·35
6	34·55	26·55	25·86	30·80	27·02	26·10	23·40	40·82	52·37
7	26·03	23·20	22·15	30·96	27·99	25·62	23·92	52·32	52·20
8	45·04	29·69	30·91	36·80	39·02	34·30	32·64	54·05	56·31
9	32·90	24·65	21·84	25·62	26·95	27·45	24·03	47·77	48·07
1850	32·26	20·50	21·87	27·32	24·62	20·94	20·11	47·99	49·58
1	25·99	22·18	20·32	25·34	23·91	22·25	22·45	41·89	47·56
2	50·87	41·14	35·55	42·67	45·43	31·00	25·30	55·19	65·35
3	38·12	28·46	23·35	28·36	30·16	26·63	21·40	36·88	39·46
4	21·81	18·27	14·88	18·12	20·73	17·75	13·81	45·46	46·13
5	28·96	25·89	19·89	18·92	28·38	22·00	20·84	36·19	34·54
6	32·97	26·63	22·33	27·30	31·43	22·63	19·49	49·23	39·48
7	31·24	28·13	23·51	25·75	29·18	27·88	23·17	40·19	38·50
8	25·86	20·50	18·36	24·80	27·71	17·50	19·00	41·02	40·23
9	34·26	32·62	22·35	30·54	26·63	25·25	20·96	46·02	48·29
1860	42·00	34·22	26·88	36·08	36·89	30·38	30·69	57·66	57·00
1	28·67	21·20	20·29	25·80	29·81	25·75	20·38	44·91	60·70
2	32·35	27·44	23·39	29·58	34·31	24·88	19·93	53·43	54·41
3	30·45	22·76	18·25	31·44	27·67	22·88	18·29	53·75	54·92
4	24·67	16·96	14·85	22·62	21·79	17·63	15·23	42·74	47·57
5	38·45	30·25	23·90	35·47	29·88	29·13	24·14	37·51	42·67
6	36·66	30·21	24·56	36·94	34·62	26·75	23·71	59·20	60·39
7	29·48	25·84	21·52	32·70	29·27	23·38	21·94	45·27	47·31
8	36·13	27·33	*25·10*	34·29	30·95	24·75	21·85	46·34	52·75
9	33·38	27·67	24·84	32·65	33·81	27·88	24·78	49·00	55·50
1870	27·57	21·64	16·60	21·74	24·17	16·88	16·40	43·47	43·09
1	33·19	23·49	20·41	32·50	30·99	25·50	21·42	40·93	50·25
2	43·21	36·28	28·31	46·00	44·16	32·50	29·20	57·59	69·18
3	31·17	23·99	21·27	33·72	25·58	19·63	19·18	42·69	49·37
4	29·01	21·63	20·19	34·74	26·74	16·22	18·09	48·67	55·11
5	35·38	29·35	31·00	38·32	37·42	32·25	25·50	43·94	46·22
6	35·31	33·15	30·86	40·30	36·15	31·00	29·51	46·10	51·86
7	45·11	32·49	28·36	33·78	33·34	24·25	24·51	60·33	65·78
8	33·34	30·37	25·90	31·48	39·54	25·63	25·58	49·79	43·76
9	36·98	34·23	30·13	34·32	34·46	24·35	25·90	42·82	43·18
1880	37·52	34·05	*28·80*	33·26	35·69	37·12	34·40	43·36	45.06
1	34·02	31·72	*24·40*	32·98	27·17	26·13	26·36	51·56	59·77

TABLE II.

Average of Table I.

Years.	Chilgrove.	Nash Mills	Oxford.	Exeter.	Orleton.	Pode Hole.	Boston.	Bolton.	Kendal.
1830–9	34·163	26·760	23·561	28·920	28·595	26·803	22·556	50·263	56·202
40–9	33·412	25·863	23·549	29·347	28·411	27·522	24·581	46·463	51·176
50–9	32·234	26·432	22·241	26·912	28·818	23·383	20.653	44·006	44·912
60–9	33·224	26·388	22·358	31·757	30·900	25·341	22·094	48·981	53·322
1870–9	35·027	28·662	25·303	34·690	33·255	24·821	23·529	47·233	51·780
1830–79	33·612	26·821	23·402	30·325	29·996	25·574	22·683	47·389	51·478

TABLE III.

Table showing Ratios of Annual to Mean Rainfall at nine English Stations between 1830 *and* 1881; *compared with the mean fall of* 1830–79 *in Table I.*

Years.	Chil-grove.	Nash Mills.	Oxford.	Exeter.	Orle-ton.	Pode Hole.	Boston.	Bolton.	Kendal.	Mean.
1830	*107*	*104*	108	90	*97*	134	114	*116*	113	109
1	*119*	*117*	118	102	92	134	113	131	119	116
2	*86*	*94*	104	88	88	113	99	114	97	98
3	*101*	*102*	92	101	98	98	100	109	108	101
4	98	81	85	74	96	71	65	93	126	88
5	92	103	102	93	91	95	96	98	109	98
6	122	116	95	101	94	104	94	114	125	107
7	80	79	83	78	95	93	104	89	94	88
8	91	86	90	109	88	82	84	101	89	91
9	120	117	131	118	114	124	126	95	112	118
1840	86	80	79	75	86	83	82	95	94	84
1	129	120	134	120	109	115	120	114	105	118
2	89	99	93	91	85	126	109	82	93	96
3	103	99	103	110	100	115	107	104	109	106
4	87	88	76	78	73	87	95	73	84	82
5	91	91	91	84	91	107	111	102	103	97
6	103	99	110	102	90	102	103	86	101	100
7	78	86	95	102	93	100	106	110	101	97
8	134	111	132	121	130	134	144	114	109	126
9	98	92	93	84	90	107	106	101	93	96
1850	96	76	94	90	82	82	89	101	96	90
1	77	83	87	84	80	87	99	88	92	86
2	151	153	152	141	151	122	112	116	127	136
3	113	106	100	93	101	104	94	78	77	96
4	65	68	64	60	69	69	61	96	90	71
5	86	97	85	62	95	86	92	76	67	83
6	98	99	95	90	105	88	86	104	77	93
7	93	105	100	85	97	109	102	85	75	95
8	77	76	78	82	92	68	84	87	78	80
9	102	122	95	101	89	99	92	97	94	99
1860	125	127	115	119	123	119	135	122	111	122
1	85	79	87	85	99	101	90	95	118	93
2	96	102	100	97	114	97	88	113	106	102
3	91	85	78	103	92	89	81	114	107	93
4	73	63	63	75	73	69	67	90	92	74
5	114	113	102	117	100	114	106	79	83	103
6	109	112	105	122	115	105	105	125	117	113
7	88	96	92	108	98	91	97	95	92	95
8	107	102	*107*	113	103	97	96	98	102	103
9	99	103	106	108	113	109	109	103	108	106
1870	82	81	71	72	81	66	72	92	84	78
1	99	88	87	107	103	100	94	86	98	96
2	128	135	121	152	147	127	129	122	134	133
3	93	89	91	111	85	77	85	90	96	91
4	86	81	86	115	89	64	80	103	107	90
5	105	110	132	126	125	126	112	93	90	113
6	105	124	132	133	121	121	130	97	101	118
7	134	121	121	111	111	95	108	127	128	117
8	99	113	111	104	132	100	113	97	85	106
9	110	127	129	113	115	95	114	90	84	109
1880	112	*127*	*123*	110	119	145	152	91	88	119
1	101	118	*104*	109	91	102	116	109	116	107

TABLE IV.

Giving the Fluctuation of the Rainfall as observed at Fourteen Stations, the Periods of Observations extending from Nineteen to Sixty years, the Variations being expressed in terms of the Mean Annual Rainfall at each Station.

Place of Observation.	Period of Observation.			Mean Annual Rainfall	Percentage of Years above the Average.	Percentage of Years below the Average.	Average fall of all the rainy Years.	Average fall of all the dry Years.	Average fall of the three driest consecutive Years.	Maximum. fall.	Minimum fall.	Extreme Range.	Proportionate No. of Periods of 3 consecutive dry Years per 100 Years.	Greatest No. of consecutive dry Years.	Average fall of the greatest No. of consecutive dry Years.
	From	To	Years.	Inches											
Calcutta	1836	1872	37	66·75	43	57	1·16	0·88	0·71	1·40	0·65	0·75	16·2	6	0·83
Bombay	1817	1872	56	76·80	45	55	1·20	0·84	0·73	1·59	0·44	1·15	17·8	5	0·84
Madras	1813	1872	60	48·60	45	55	1·28	0·77	0·65	1·82	0·38	1·44	21·7	9	0·76
Nagpur	1854	1872	19	37·52	53	47	1·17	0·80	0·79	1·43	0·51	0·92	21·0	3	0·79
Mauritius	1853	1872	20	42·95	50	50	1·20	0·80	0·67	1·60	0·48	1·12	20·0	3	0·67
Barbadoes	1843	1863	21	56·07	38	62	1·21	0·87	0·84	1·35	0·76	0·59	19·0	4	0·87
Adelaide	1839	1860	22	21·80	41	59	1·20	0·85	0·80	1·40	0·68	0·72	22·7	5	0·84
Hobart Town ...	1841	1870	30	22·71	53	47	1·19	0·77	0·78	1·79	0·59	1·20	16·6	3	0·78
Cape Town	1842	1872	31	24·21	45	55	1·17	0·86	0·78	1·52	0·77	0·75	19·3	5	0·82
New York	1836	1854	19	42·77	42	58	1·22	0·84	0·81	1·53	0·64	0·89	21·0	6	0·84
Rome	1821	1860	40	30·18	50	50	1·20	0·80	0·73	1·55	0·43	1·12	25·0	6	0·81
Greenwich	1820	1872	53	25·04	45	55	1·17	0·85	0·81	1·45	0·67	0·78	22·6	5	0·81
New Bedford, U.S.	1814	1855	42	41·40	38	62	1·18	0·89	0·86	1·40	0·74	0·66	23·8	9	0·90
Prague	1832	1870	39	16·44	54	46	1·14	0·83	0·74	1·44	0·58	0·86	17·9	4	0·95
General Averages					45·8	54·2	1·19	0·83	0·76	1·52	0·59	0·93	20·3		0·82

CHAPTER II.

CONSTRUCTION OF WELLS.

Surface Wells.—Preliminaries.—Sinking by Underpinning.—Suspended Shield.—By Building on Curbs.—Galleries in Wells.—Sanitation of Wells.—Deep Wells.—American Practice.—Pumps.—Suction, Centrifugal, Pulsometer, and Chain Pumps.—Motors.—Steam.—Gas.—Wind.—Water.—Rams.—Pohle Air Lift.

To enter fully into all the questions involved in well construction would require a volume to itself. It is proposed here to deal with the most important points; for further information the special books mentioned in the list of books of reference should be consulted.

The water from *deep* wells has the advantage over other sources of supply in that it is free from organic pollution. That from *surface* wells, however, is often quite the reverse, and is too frequently impregnated with decaying organic matter in a degree injurious to health. This is a matter of much importance, especially to the Indian engineer, inasmuch as the great mass of the water supply is there derived from wells sunk in the porous alluvial stratum overlying a vast portion of that country. We have, therefore, to consider in such cases not only how to construct, but also how to protect the well from contamination. The frequency of enteric fever cases among the troops in Indian cantonments has made this a matter of vital importance.

Construction of Surface Wells.

Surface wells may be sunk either by (*a*) under-pinning, or (*b*) by excavating in the shaft below, and simultaneously building the lining above. These operations will now be described.

In either case, a site having been selected, a circle is marked upon the ground, the diameter being equal to the bore of the well, plus twice the thickness of the proposed lining or *steining*. In some cases, wells of small diameter (not greater than 6 feet) can be sunk without any steining at all, and in some cases in India the steining only goes down for a few feet, to protect the edges of the well at the top. There is, however, no doubt that for drinking water steining is most necessary. If properly constructed it will exclude the infiltration of objectionable fluid. Unlined wells are really only permissible in temporary work, *e.g.*, when a well is sunk near a large bridge to supply water for the masonry and work-people during construction. The steining should be carefully constructed ; it need not be absolutely smooth inside, indeed it is better not to be so,* but it should be water-tight. Any shrubs or plants growing on the sides should be removed and the crevices caused by the roots cemented up. Many cases of well pollution have occurred in India owing to the roots of trees forcing their way through the brickwork, and thereby affording a channel for surface impurity. The bricks forming the steining should be laid truly cylindrically, generally in English bond, backed sometimes with concrete or puddle. A ring or two of brickwork in cement at intervals of 5 to 10 feet vertically is useful for strengthening the whole, but is not a necessity. Where specially good work is required in the lining of wells, it is advisable not to use ordinary bricks, with varying thicknesses of mortar joints, but to have specially moulded bricks. *Plate* III., *Figs.* 6, 7, 8, and 9, give details of such special bricks, and the method of laying them, for 8 feet and 10 feet wells. Care should be taken to break joint by laying each course half the width of a header back from that below. The number of special bricks required in each ring is shown on *Plate* III. In India some steining is made in earthenware rings 5 inches to 6 inches deep, supplied in quadrants, and set to break joint.

To construct the whole truly it is necessary to have accurate gauging of the centre. Masonry pillars are sometimes built in prolongation of a diameter, and a straight-edge laid across, with a notch marking the exact centre of the cylinder. From this notch the true centre can at any time be determined (and should constantly be checked during construction) by a plumb-bob, which should be heavy, suspended from strong fine cord, such as salmon line.

Sometimes when the well is sunk through stiff soil the excavation is carried down for a considerable depth without steining, and the steining subsequently built in. If this is done, the edges of the well should be protected by a wooden platform, or by baulks let into the ground on the surface to distribute the weight of persons and materials at the edges.

Sometimes in sinking, a layer of sandy loose soil is found to intervene between two stiff layers. To hold back the loose stuff the

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* On account of frogs, which in a perfectly smooth well get no footing at the sides, die, and pollute the water.

natives of India sometimes use rings or segments of earthenware, as described above. Another and equally effective plan is to make gabions of a diameter equal to the bore of the well. This expedient is, of course, only applicable to unlined wells, or for very temporary purposes.

To construct a well *by underpinning*, a shaft is first constructed at full size to such a depth as the soil will stand without support. A curb or flat ring of wood (usually oak or elm 3 or 4 inches thick, and of a width equal to the thickness of the steining) is laid at the bottom of the shaft, and the steining built upon it. This completes the first section of the work. In the centre of the pit thus completed another small shaft is dug to about the same depth as the first. A hard wood block is placed in the centre at the bottom of this pit, sometimes on a small wooden platform, and raking props are inserted under the completed steining, butting against the central block. Sufficient earth is cut away to enable these props to pass from the central block to the steining. The curb, with its load of brickwork, is thus temporarily supported by the props, and it is then possible to enlarge the pit to the full size. Another curb is then set, and new brickwork built to form a permanent support to the first section. The props are then removed, and the operation repeated (see *Figs.* 3 and 4).

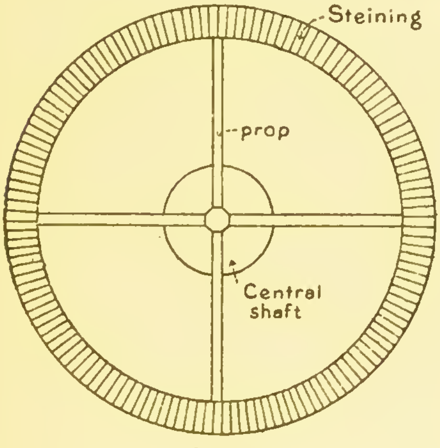

Fig. 3.

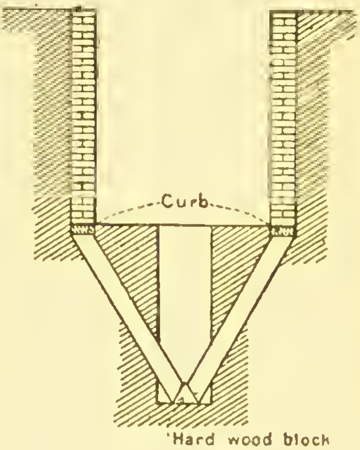

Fig. 4.

In some cases the soil is sufficiently stiff to enable this to be done without the raking props, excavating the well to the full internal diameter, so that the earth underneath the curb supports the brickwork above. When the soil is at all treacherous this is dangerous, because when the earth begins to give way at all it is likely to fall in a considerable mass, and injure the workmen below. At the same time, the work has the advantage of being more quickly carried out than with the raking props. To secure this advantage, and at the same time protect the workmen, a method has been devised of using a suspended shield of cast-iron segments, bolted together by internal flanges, the whole being of a diameter slightly less than that of the completed well. The suspended shield may also be made of wood, as in *Plate* III., *Figs.* 3, 4, and 5. The cylindrical shield is suspended from a staging above, and raised or lowered by blocks and tackle. *Fig.* 5 shows a section of this method. When the excavation has proceeded to the full extent of the shield, recesses are made in the earth under the existing steining, and brickwork built in them (*vide* the shaded portions of the ring in *Fig.* 6). The brickwork previously constructed is thus supported at intervals all round, the intermediate earth is then cut away, and the whole section of steining completed.

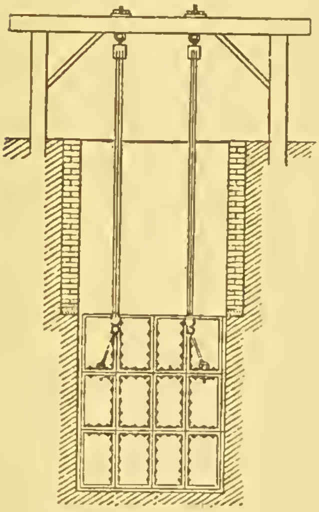

Fig. 5.

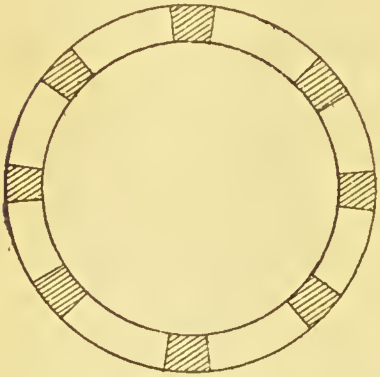

Fig. 6.

In India most of the large wells are constructed by the second method, *i.e.*, by building the steining on curbs of wood or iron, or a combination of both, with a cutting edge (see *Plates* II. and III., *Figs.* 1 and 2. The former was used in the Indian State Railways for well foundations). The masonry is built above ground and the well excavated from beneath the cutting edge. The weight of the gradually-increasing load forces the curb down, so the digging of the well below and the building of the steining above go on simultaneously. The great difficulty in such cases is to ensure the vertical sinking of the shaft. The frictional resistance of the earth at great depths is estimated at ¼ ton per square foot of surface. The friction of the earth against the sides of the well may act unequally and cause the shaft to become out of plumb. Various expedients for rectifying this are mentioned in Sir G. L. Molesworth's lectures on "Railway Engineering" at the S.M.E., and need not be further detailed here. One method, however, adopted by Mr. H. Footner (Chief Engineer, London & N.W.R.) in sinking cylinders for a bridge over the Tame, is worthy of mention (see *Fig.* 7). The well is fitted with an iron cap A, which has angle-iron flanges of such a size as will admit four ring-bolts *aa*, of large diameter, passing through them. These ring-bolts are connected with a frame BB, which is slung or suspended from a staging CC, resting in the ground on piles or other secure foundation. The frame BB is connected with CC by bolts *bb*, and is loaded with any amount of weights WW. By turning the nuts *bb* the weights can be transferred either to the staging CC, or to the cap AA. Thus the sinking of the cylinder can be adjusted with the greatest nicety, and the actual weights applied need never be more than a few feet above ground, so that in event of the whole thing going down with a run, no injury may be expected to life or plant in the vicinity by the falling of the weights.

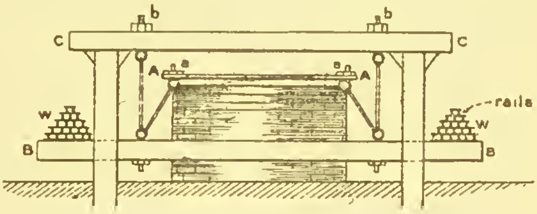

Fig. 7.

If it is absolutely impossible to get a well down by the above, or similar means, a smaller well may be sunk in the interior of the first.

Besides brickwork, other materials are sometimes used in well steining. Stone requires more labour in preparing than brick, hence would only be used in localities where stone is abundant, and, as a rule, such localities do not depend on wells for their water supply. When stone is available for this purpose only such qualities as absorb little water should be used.

Timber steining is objectionable, because liable to decay, and, therefore, it tends to pollute the water. Iron is sometimes used, and is especially useful when sinking shafts through a wet stratum is necessary.

The coverings for wells, when such are required, may be somewhat as shown in *Plate* III., *Fig.* 14. *Plate* III., *Figs.* 10 to 13, show attachment for pulley wheel for bucket or *charsa,* the leather bag, holding about 20 gallons, and drawn up by oxen going down an inclined plane, used largely in Northern India.

The ventilation of well shafts during construction is a matter of importance, especially when explosives are used in excavation. A miners' bellows may be found sufficient, but in large workings sometimes it is necessary to let down a 4-inch or 6-inch pipe, and connect it at the top with a steam jet or furnace chimney, so as to force a draught upwards. This will draw out the foul air and cause fresh air to rush down and replace it.

Galleries in Wells.

Horizontal galleries driven from the bottom of the well shaft are often employed with success to increase the yield of the well. Such galleries should be at right angles to the general direction of the subterranean flow if such direction can be ascertained, so as to intercept the water passing down.

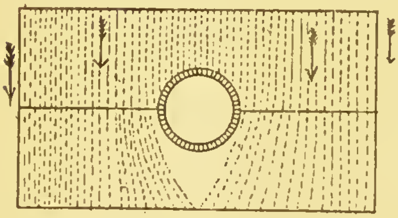

Fig. 8.

Thus in *Fig.* 8 it will be evident that a gallery in a *transverse direction* to the arrows will intercept a greater amount of water than would find its way into the well shaft alone. When the strata are horizontal and there is no flow across, the galleries may radiate from the well shaft all round. The size of such galleries is limited by the least dimensions in which men can work comfortably. The most economical cross-section is oval, about 5 feet maximum height by 3 feet wide, though a horseshoe form with flat bottom is sometimes given. *Fig.* 9 shows further details of such galleries.

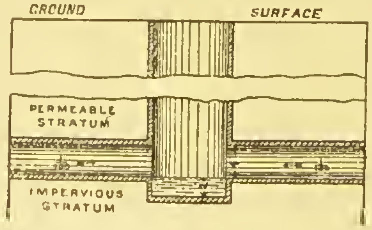

Fig. 9.

Figs. 10 and 11 show details of well and galleries for supplying the town of Freiburg in Germany. The pipe issuing from the well to the left of *Fig.* 10 is the supply pipe taking the water to the town by gravitation.—(Lueger, p. 356).

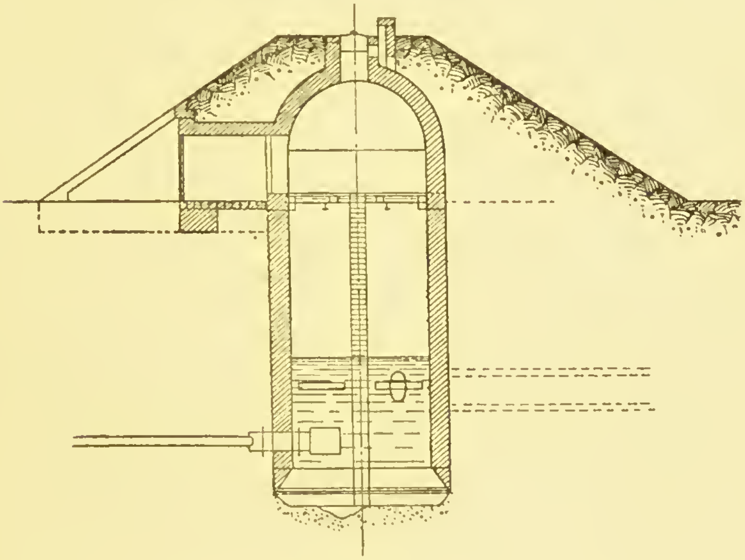

Fig. 10.

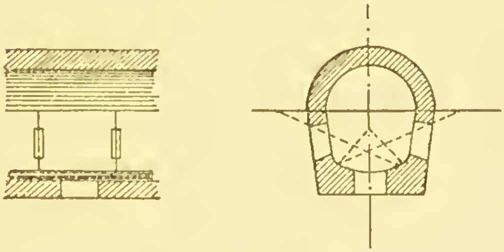

Fig. 11.

These galleries are also frequently formed parallel to the banks of rivers or lakes, connecting sometimes a series of wells sunk in the vicinity of such sources of supply. The galleries intercept land water flowing towards the river, or act as "filter galleries," collecting the water from the river, which, to a certain extent, is purified by passing through the soil intervening between the gallery and the river.* This is done in many places, *e.g.*, the supply for Windsor Castle is obtained from wells sunk in the valley of the Thames.

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* See *Principles of Waterworks Engineering*, Tudsberry and Brightmore, p. 117.

It may be here interesting to give a brief account* of a well recently constructed at Webster, Mass., for obtaining water in a coarse, gravelly formation near a lake. The steining of the well is a dry stone wall 5 feet thick for the lowest 3 feet, and then reduced by an inside offset to 3 feet 8 inches for the remainder of the depth, which is altogether 30 feet. The diameter of the well is 25 feet. The shoulder of the offset forms a support for a 12-inch lining of brick in cement. The top 4 feet of the stone wall was built in cement, and a coping is given of heavy stones 3 feet long, 3 feet wide, 1 foot thick. During construction, the water was kept down by a 6-inch centrifugal working continuously. The estimated flow —1¼ million gallons per diem—was measured by the discharge of this centrifugal into a tank with a weir overflow, whereby the discharge was measured.

Some of our cantonments in India are supplied from large wells thus sunk near rivers. Experience has shown that in such cases two precautions have to be taken—first, to ensure by training works that the river will not change its bed; and second, to see that the position of the well relative to the river and to the geological section of the ground is such that the water from the river will find its way into the well, and not be prevented by the intervention of some impervious stratum.

Sanitation of Surface Wells.

Before leaving the subject of surface wells, it may be advisable to consider certain matters connected with them, which are important from a sanitary point of view.

Some authorities on water supply have, indeed, dismissed the whole subject by classifying surface wells under the heading of "dangerous sources of supply," and, therefore, to be condemned as insanitary. But this hardly suits our purpose, because in very many cases there is no other source of supply available, and our attention must, therefore, be directed to the method of making the best use of them and obviating any polluting cause.

Surface wells may be polluted (*a*) by the infiltration of foul surface water; (*b*), by the decay of vegetable matter which has fallen into the wells; and (*c*) by stagnation of the water at the owing to the well being little used.

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* Taken from *The Engineering Record*, 6th April, 1895.

Another cause of impurity may be the want of cleanliness on the part of the vessels used to draw the water. The skins or *musaks* used by the native water-carriers with the troops in India are not always above suspicion, and must be periodically inspected. This, however, is a matter for regimental and cantonment officials to deal with, and is not an engineer's question.

As regards the causes above mentioned, there is no doubt that if an unlined well be situated near inhabited buildings, farmyards, etc. (especially in the East), it is bound to be polluted and rendered totally unfit for drinking. If the masonry lining is absent—as it nearly always is in the village wells of India—the well becomes little better than a cesspool. On the other hand, if the steining be water-tight, and the soil a good one, the surface impurities are subject to a thorough filtration before they can reach the well. Hence the necessity of keeping the steining of wells in good order. Especially near the ground surface should the well tube be water-tight. This may be done by casing the masonry in puddle or concrete, or building the steining in cement. The tube should be raised 2 or 3 feet above ground (see *Fig.* 12).

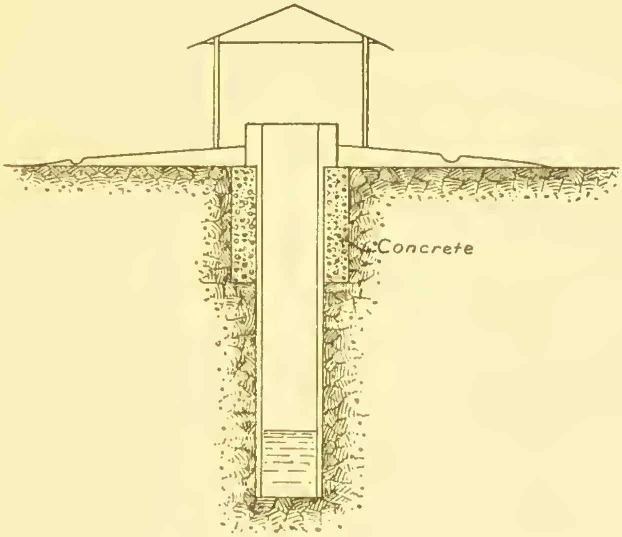

Fig. 12.

The pollution caused by the accumulation of vegetable matter is very common. Wells are not infrequently situated in groves, or near trees, the leaves of which, falling into the well, produce a layer of decomposing vegetable matter most injurious to the quality of the water. A simple remedy is to construct a small cover to the well; galvanized iron on iron standards would probably be the best material, but such protection is, it must be admitted, rarely seen. No doubt its application in many cases of cantonment wells would be a feasible and fairly cheap way of utilizing existing sources of supply when more expensive and elaborate schemes are not possible for lack of funds. The accumulation of deposit at the bottom of Indian wells might be profitably cleaned out periodically by the use of a portable dredger slung from a cart.

The prevention of stagnation is a matter of much importance in connection with camping grounds and wells on the trunk lines of march. How often the germs of disease are brought into a cantonment by a regiment which has marched in, obtaining its supply day after day from stagnant wells, it would be impossible to say. The remedy for such a case lies not with the engineer, but with the civil administration, who can arrange for the local cultivators to use the water in these wells for their own purposes when not required by the troops. It is, however, necessary to point out that when an engineer officer is called upon to report on the suitability of a line of march where the camping grounds are to be supplied from wells, he should ascertain whether these wells have been regularly in use or not. If not, they cannot be considered fit sources of supply to troops, unless cleaned out by an advance party.*

Surface wells, however, are a less satisfactory source of water supply than almost any other, and in our large Indian cantonments they are to a very great extent being superseded by water brought from rivers, or other sources of supply, and properly filtered. That the introduction of such water has been beneficial to the health both of the troops and the civil population has been most distinctly proved in many cases. One of the most notable of these was at Rawal Pindi, where an outbreak of cholera occurred at a time when the water supply works were only half completed. It was proved beyond a doubt that those houses where cholera cases occurred were those which had not been brought into connection with the new water system, and were still dependent on wells (*Minutes of Proceedings of the Institution of Civil Engineers*, Vol. CXVI., p. 300).

DEEP WELLS.

It is not intended here to go into the many questions involved in the sinking of deep wells. The subject is dealt with in Part V. of the *Instruction in Military Engineering.* Much information as regards English practice may be obtained from Mr. Spon's *Practice of Sinking and Boring Wells,* Messrs. Turner and Brightmore's *Principles of Waterworks Engineering,* and Mr. Mansergh's lectures at the S.M.E., published separately in pamphlet form by the R.E. Institute. There is also an excellent practical article on the subject by the late Major Jebb, R.E., in Vol. V. of the *Professional Papers* of the Corps of R.E. (1841), from which several hints have been borrowed for this work. The practice of boring for water at Chatham was introduced by Colonel Sir C. Pasley in 1835, and much valuable experience has been gained by the officers and men of the Corps in this useful branch of engineering since that date.

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* I am indebted for the above remarks on the sanitation of wells to Brigade-Surgeon R. Pringle, M.D.

As the matter has already been treated in the articles above alluded to, it only remains to supplement the information there given by a few remarks derived from American experience, as given by Mr. Trautwine.

The cutting tool used in America for drilling the deep vertical holes, 6 inches or 8 inches diameter, required for artesian wells, differs somewhat from that ordinarily used in England. The American tool (called a "Z" bit from the shape of its cutting edge) is partly revolved horizontally, blow after blow, and thus the hole perforated is cylindrical. *Fig.* 13 shows this tool; the cutting edge is about 6 inches wide, and is larger than the diameter of the rod, so as to decrease the chance of jamming. For comparison, the English cutting tool is shown in *Fig.* 14. *Fig.* 15 shows an English earth scoop.

A simple arrangement for preventing the cutting tool from becoming wedged at the bottom is shown in *Fig.* 16. One of the bars or links which connect the cutting tool with the drilling cable above is arranged with a slot and link, about 12 inches long. When the cutting tool jams the drilling is stopped and the cable slackened off, thus the link drops to the bottom of the slot. The cable is then again started and the jerk thus given in an upward direction loosens the tool.

To prevent the cable from being twisted with the rotatory action of the cutting tool, a motion is given to it from above, which turns it about one-fifth of a revolution at each downward stroke.

Another form of American borer is that made by the Pierce Artesian and Oil Well Supply Co., 80, Beaver Street, New York, for "soils, clay, sand or gravel, but not through hard rock or large boulders." It consists* of two sheet-iron cylindrical segments SS, called "pods," having their lower or cutting edges shod with steel.

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* This description is taken from Trautwine's *Pocket-Book*, p. 626.

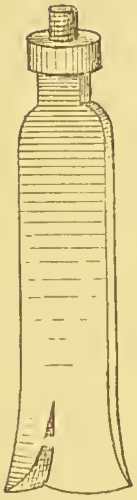

Fig. 13.

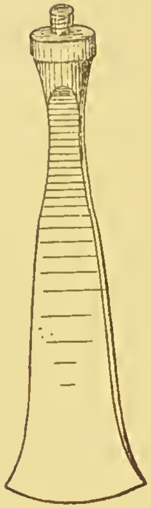

Fig. 14.

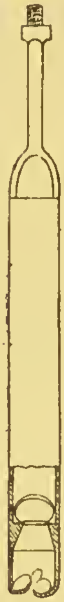

Fig. 15.

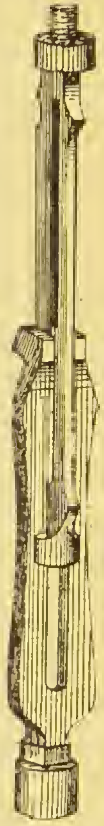

Fig. 16.

These edges project (as shown in *Fig.* 17) beyond the sides of the auger, and thus make the hole larger than it, so that it cannot bind or stick. At *a* the auger is attached to the lower end of a vertical boring rod. At the top of this boring-rod is a swivel-hook, by means of which the entire apparatus is hung to the end of a rope, which passes over a pulley at the top of a derrick or tripod, and down to a drum worked by a windlass and gearing. By means of this drum and rope the auger and boring-rod are lifted, and suspended over the intended hole.

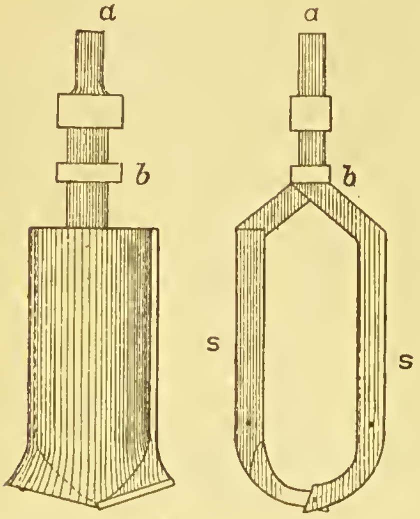

Fig. 17

The auger is then lowered, and rotated horizontally by two men or one horse, working at the ends of levers which grip the boring-rod a few feet above the ground. The swivel at the top of the boring-rod permits this rotation to take place without twisting the rope. The shape of the auger is such that its rotation feeds or screws it into the ground, and the man at the windlass has, during the boring, merely to keep the rope tight, so as to prevent the auger from boring too fast, and becoming clogged. In about eight revolutions the auger fills with earth. By means of the windlass it is then raised to about 2 feet above the ground, and by unkeying and removing the band *b* the auger is opened like a pair of tongs, and the earth emptied. The boring then proceeds as before. When the boring has reached a depth of about 10 feet, a second bar must be added to the top of the rod. Additional lengths of boring rod are attached from time to time, as required by the descent of the auger.

The borers are made from 6 to 18 inches diameter, or larger to special order. If desired the boring may be made from 24 to 36 inches diameter by attaching a reamer to the auger. This auger will bore to a depth of 100 feet or more, at the rate of from 5 to 20 feet per hour. It removes stones as large as half the diameter of the hole. In dry soils a bucketful of water is poured into the hole each time the auger is raised. The size of bore holes is of more importance in artesian than ordinary wells, whence water is raised by pumping. In the former case, however great the available amount may be, the supply will be only that which the pressure at the bottom of the bore-hole over that due to the column of water in it can force through a tube of the length, diameter, and roughness of the bore-hole, according to ordinary hydraulic laws. Whereas in the latter case, where artificial power is employed, the height to which the water naturally rises may be reduced by pumping at a greater rate, and the percolation into the bore-hole may be correspondingly increased under the additional head thus produced.*

The advantages of the deep well system for purity, and not infrequently for certainty of supply, are so great that in some countries—notably in the United States—the careful geological survey necessary for the exact knowledge of where and how deep such wells should be made has been made a national question. The absence of such knowledge has made well-boring in many parts of

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* Turner and Brightmore, p. 120.

India less common than it might otherwise have been. At Lucknow, for instance, an artesian boring was carried out to a depth of 1,336 feet without water being reached, and through alluvial soil the whole way*—a depth of formation probably unique in such operations. Some small borings have, however, been successful at Quetta, and one on a larger scale at Port Canning, near Calcutta.

The importance of such wells, from a military point of view, is obvious, inasmuch as they can frequently be made within the limits of a fortified enclosure, where it is essential that the garrison be independent of external arrangements for their water supply, and where, from the very nature of the position, other sources of water supply would be impossible. Thus at one fort in the South of England, surrounded by sea, the supply is entirely obtained from a bore-hole sunk some 400 feet into the chalk. Other well known forts on a salt marsh obtain their supply from similar wells. The supply is raised by double-action force pumps, capable of raising 1,000 gallons per hour each. These pumps are similar to the one shown on *Plate* IV., and are worked by two men turning handles.

Raising Water from Wells.

The various sorts of pumps used for raising water may be classified as follows:—1. Atmospheric, or suction pumps. 2. Centrifugal pumps. 3. Pulsometers. 4. Chain pumps.

Although it is not intended to give in this work a full description of the pumps required for waterworks (a subject which would require a large volume to itself), yet some general description of each of the above classes is, no doubt, desirable, so that the suitability of any class may be taken into account in any given case. For it is evident that in a very large number of cases the nature of the pumping machinery, and the economy of working thereof, will be one of the most important factors in a water-supply scheme. To leave the subject out of the question is, therefore, hardly wise, although it is not intended here to enter into details of construction.

1. *Atmospheric pumps* are those of the familiar type, which work by the exhaustion of air inside a cylinder, and the pressure of the atmosphere on the surface of the water in the well. The simplest form, known as the "common suction" pump, consists of a cylinder, attached to which is a suction pipe reaching down

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* Wallace, *Sanitary Engineering in India*

into the water of the well, and furnished with a valve, technically called a "clack" (B, *Fig.* 18) opening upwards. The air-tight piston worked by the vertical piston-rod has also in it a valve (A, *Fig.* 18) opening upwards. When the pump is first put in operation the cylinder is full of air, but the action of the piston exhausts the air inside the cylinder, and the atmospheric pressure on the surface of the water causes the water of the well to rush into the vacuum thus formed. Each down stroke of the piston-rod closes the clack B, and opens the valve A, and *vice versa.* The water is thus raised at each successive stroke until it reaches the top of the delivery pipe.

Water can be raised by this form of pump to any required height, as long as *the height of the clack* is not more than about 25 feet above the lowest level of water in the well. The best results are obtained with heights of 10 feet to 15 feet, and with high speeds the shorter the suction the better. Theoretically, atmospheric pressure is capable of supporting a column of 33·9 feet of water; practically, one cannot obtain the perfect vacuum necessary for this.

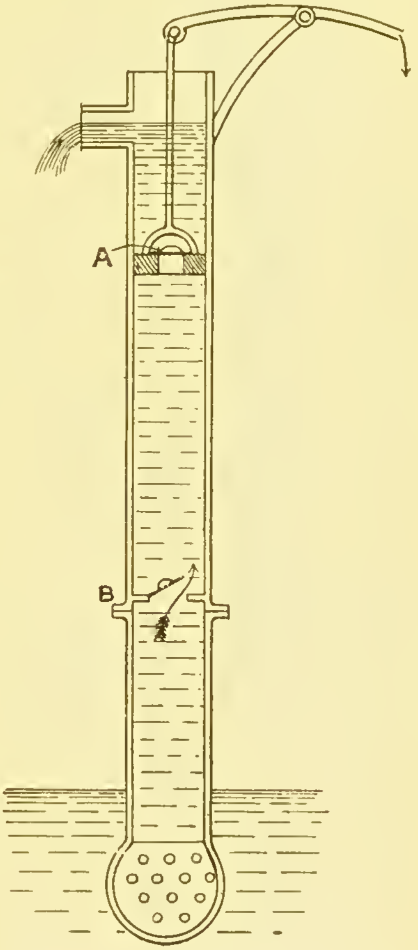

Fig. 18.

"The price of the ordinary lift-pump, with a working barrel 3 inches in diameter, complete, for a depth of 30 feet, is £5, and from 2s. 6d. to 2s. 9d. per foot beyond that depth. The capacity of this pump when worked by hand is equal to 400 gallons per hour lifted from a depth of 30 feet."*

Force or plunger pumps are used where the water has to be forced to a height. A force pump consists of two barrels, one similar to the common pump, one rising by its side (*vide Fig.* 19). These barrels may be either horizontal or vertical. The action is as follows :—The water is first raised in the suction pipe, in a similar way to the common suction pump, except that the piston has no opening valve, and the air is forced out through the valve A into the adjoining air chamber. Through this valve the water is also forced, and the pressure of the descending piston causes it to flow up the rising pipe. When the water rises in the air vessel it compresses the contained air, which, being elastic, reacts upon the water, producing a continuous flow. The air vessel thus prevents the shock to the working parts, which would otherwise be caused by the force required to overcome the inertia of the water, and it also helps to economize the engine power by keeping the water in constant motion.

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* *The Builder*, August 18th, 1894. In this periodical there were in 1894 a series of most useful articles on water supply, from which much valuable information has been derived.

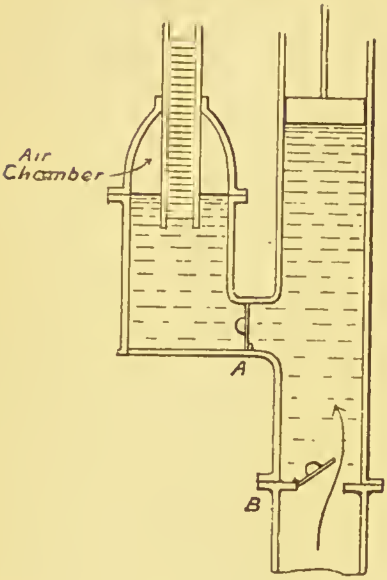

Fig. 19.

This form of pump is specially suitable when the water has to be raised to a considerable height, or when continuous working is required.

A modification of this pump, very largely used in waterworks, is shown in *Fig.* 20.* It has a solid plunger piston working through an air-tight stuffing box in the cover of the cylinder, and having a sectional area equal to one-half that of the working barrel. The theoretical quantity of water which rises into the working barrel at each up-stroke of the bucket is equal to the capacity of the barrel through which it ascends, one-half of which quantity rises in the delivery or rising main on the descent of the bucket, and the remaining portion is discharged during the following up-stroke. The delivery from the pump is, therefore, continuous. This is one of the best forms of double-acting pumps. The quantity of water delivered at the up and down-stroke is no more than from a pump with single action, the difference being that the double action gives a continuous, and the single action an intermittent delivery. This form of pump is used in many large waterworks.

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* This description is taken from *The Builder*, August, 1894.

Another form of plunger pump is shown in *Fig.* 21.* The valve

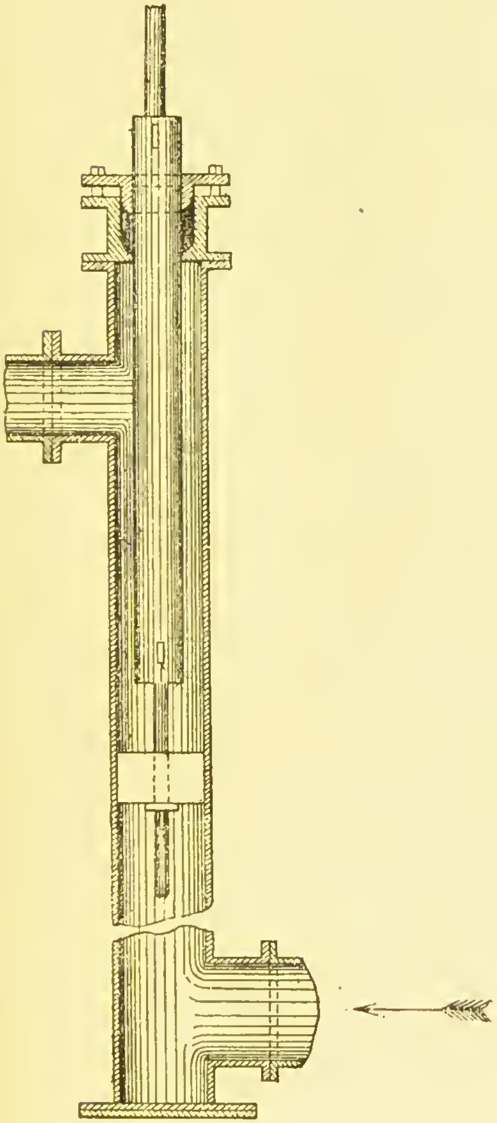

Fig. 20.

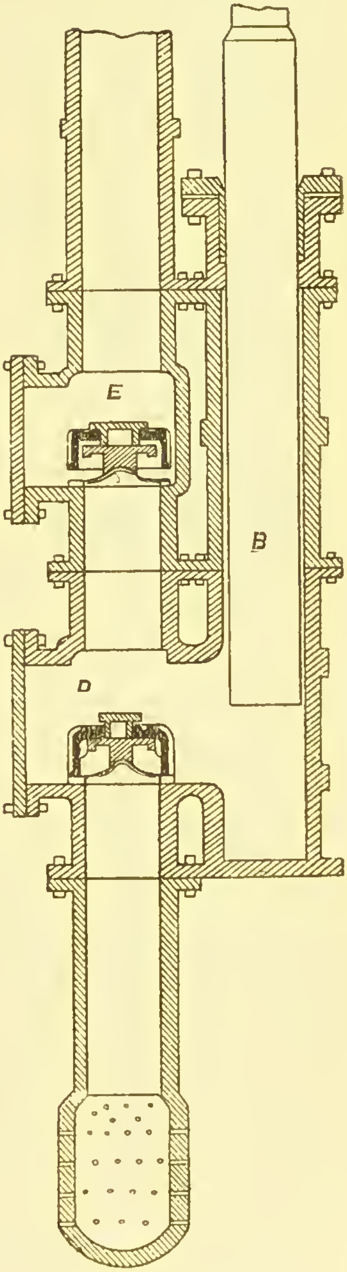

Fig. 21.

D in this case closes as the plunger B descends, and opens as it ascends. At each stroke a quantity of water equal to the volume of the plunger is forced through the valve E. It will be seen that the valve D must not be higher than 25 feet above the surface of the water. The delivery pipe may be connected with an air vessel.

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* Taken by permission from *Waterworks*, by S. Hughes.

The action of the double lift and force pump, which sends water up the delivery pipe at both the up and the down stroke, is shown in *Fig.* 22.

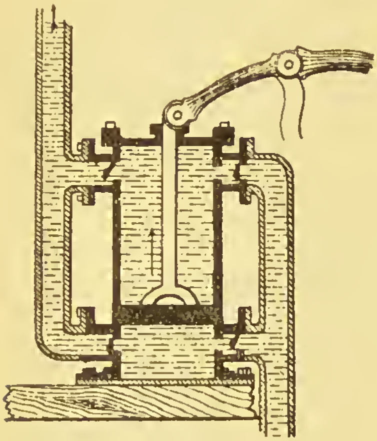
Fig. 22.

It is evident that the flow of water with a single-barrel pump will be intermittent, and that a great deal of the efficiency will depend on the condition of the one piston. When the power is applied by cranks or eccentrics on a revolving shaft at the top of the well, it is therefore economical to have more than one barrel, although there may be only one suction pipe, and only one delivery pipe. Usually with steam power there are three barrels side by side, worked by cranks at an angle of 120° on one shaft (see *Plate* VII.).* Each barrel has its own clacks and valves, but there is one suction and one delivery pipe. It is not advisable to have more than three pumps in one set, or to have a size exceeding 8 inches to 9 inches diameter with a 24-inch stroke. If more power is required an extra set of pumps should be provided. Slow speeds of working are advisable: for 3 inches or 4 inches diameter, 30 strokes; 5 inches and 6 inches diameter, 20 strokes; and 7 inches, 8 inches and 9 inches diameter, 16 to 18 strokes per minute,* are the maxima that should be given.

Double-throw pumps, with 3-inch barrels and 10-inch stroke, can be arranged so as to be worked by a horse, travelling at an average rate of three miles an hour, and making 20 strokes a minute. Such pumps are sold by any of the well-known firms who make pumping machinery.

The following table (taken from *The Builder*, August, 1894) gives particulars of the approximate quantities, in gallons, per hour raised by pumps. These are supposed to be working at a uniform speed of 20 strokes per minute :—

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* *Pumps and Pumping Machinery*, Frederick Colyer. This plate has been reproduced here by Mr. Colyer's kind permission.

Diameter of pump.	Length of stroke.	Single barrel.	Double barrel.	Treble barrel.
Inches.	Inches.			
2½	9	165	330	495
3	9	240	480	720
3½	9	310	620	930
4	10	480	960	1440
4	12	575	1150	1725
5	12	900	1800	2700
5	15	1125	2250	3375
6	12	1280	2560	3840
6	15	1600	3200	4800
6	18	1920	3840	5760

2. *Pulsometers* (*Plate* V.) are more used for temporary than permanent work, but are in any situation most useful. Steam is introduced through a flexible pipe from a boiler, which may be at some distance from the water to be raised. It is thus possible to suspend the pump by chains, from a tripod or other support, in any convenient position, *e.g.*, in a well near the surface of the water, and take the steam to it when so suspended. The apparatus consists of two pear-shaped vessels AA, with a ball valve B at the top. The steam enters at C. The vessels AA, at starting, are filled with water; the steam is then admitted, closing one vessel by the ball valve and pressing the water in the other to the level of the delivery valve D. The steam inside A is condensed by contact with the cold sides, causing a vacuum to be formed, and bringing the ball valve over, causes the other port to open to steam, and water meanwhile enters the first vessel by the suction valve E.

The most important points about the practical working of pulsometers are—(1), to ensure thorough jacketting of the steam pipe so as to prevent condensation of the steam in its passage to the apparatus; and (2), to have the pump near the surface of the water.

Thus alternate condensation and discharge takes place on either side of the vessel, causing continuous pumping as long as steam is supplied.

The simplicity of this pump, and its adaptation to different circumstances, commend it for military purposes. It is possible to have the whole apparatus, including vertical boiler, steam pipe, and a derrick for hoisting or lowering, mounted on wheels. Such a portable apparatus has been approved for use in the R.E. Railway Companies.

For constant stationary work, however, pulsometers are not recommended.

It must also be stated that the mere fact of lowering the pump into a well, so as to be near the water surface, is not confined to this pattern only. The atmospheric lift and force pump can also be constructed so as to be either slung from chains, or built on a platform in the interior of a well.

3. *Chain Pumps.*—"Chain pump" is the general name given to a class of apparatus whereby the water is raised by an endless chain passing round a vertical wheel above the well and dipping into the water below. This chain either (*a*) carries a series of buckets throughout its length, as in the case of a dredger, or (*b*) has a number of diaphragms large enough to work inside a tube (*vide Plate* VI.) which dips into the water. The chain rises through the tube, and in so doing the diaphragms lift the water.

In either case the water is poured out as the buckets or diaphragms cross the top of the lift. To this class of well any motor may be applied that will cause the chain to revolve. The Persian wheel, well known in the East for raising water, belongs to this class of pump. Here there is a series of small earthen pots on a chain passing over one wooden vertical wheel geared to another wooden wheel worked horizontally by oxen slowly pacing round, and usually much of the power is expended in overcoming the friction of the primitive machinery.

An ingenious adaptation of this principle is common in Burmah, where water is raised automatically from a river to the top of a bank by a wheel with bamboo buckets on the periphery. These act both as paddles and buckets. The current causes the wheel to revolve, and buckets, full below, discharge at the top.

Chain pumps are generally suitable for raising water which has become foul or gritty.

4. *Centrifugal pumps* are not very suitable for the slow, steady

work required for water supply purposes, but are specially adapted for the drainage of land, of the foundations of bridges or other masonry structures, and all cases where large quantities of water have to be raised through a moderate lift, not exceeding about 25 feet. They have the advantage of being compact and requiring little repair. Having no valves, they can be used for pumping liquids containing solid matter in suspension. The apparatus (shown in *Fig.* 23)* is extremely simple, consisting of revolving fans, which, by their rapid revolution, cause a vacuum, draw water through a suction pipe into the centre of a rotating wheel, and by centrifugal action cause it to be ejected through a delivery pipe. The revolution is given to the fans by belting passing round the fly-wheel of an ordinary steam engine, so that it is possible to use this pump with portable as well as stationary engines. As there is a considerable pull on the belting, the pump has to be firmly secured to the staging over the well or sumpt whence the water is pumped.

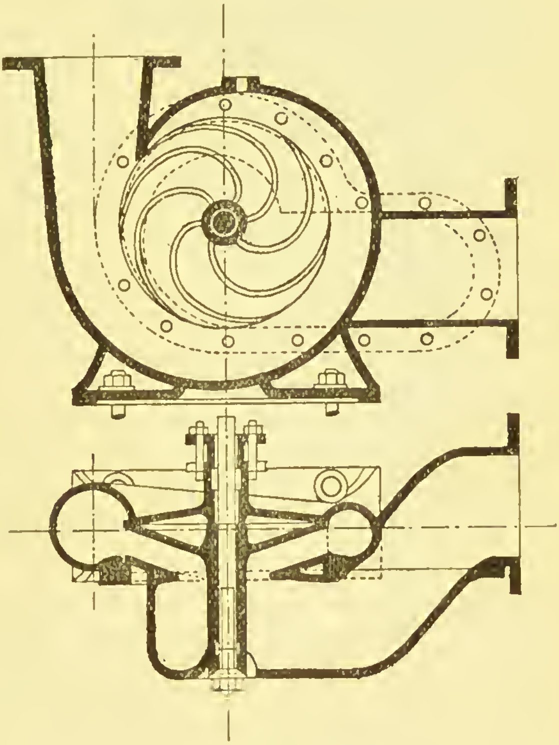

Fig. 23.

5. *Archimedean screw pumps* have also been used of recent years with much success for moderate lifts. Here there are several spiral blades working round a central core, the whole being inside a sheet iron cylinder, which revolves, and is inclined to the horizon at an angle of from 15° to 30°. Spur or bevel gearing at the upper end of the cylinder, giving it motion, is actuated by a steam engine.

Of the above different sorts, the lift and force pump as in *Plate* VII.

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* Lueger, p. 647.

is probably the most suitable for water supply work from wells. Slow, steady work is here required, and hence pumps of the centrifugal or Archimedean screw pattern are unsuitable. The pumps should be fixed near the side of the well, and duplicate sets of the various parts should always be provided to allow of examination and repairs. As men may have to go down the well while the pumps are working, room should be left for them to descend between the pump rods. *Guide rollers* should be provided for the pump rods at vertical intervals of 7 feet or 8 feet. These rollers should be supported on girders built into the steining. *Staging* in pump wells should be at intervals of about 10 feet, and should, if possible, be of iron ; wood rots, and is slippery after a time. Open iron gratings on girders are the most satisfactory. The stairs or ladders should be of iron. The girders for supporting the staging may be the same as those which fix the guides for the pump rods. All girders should be well built into the sides of the wells, supported on stone templates, and pinned with Portland cement.

At the level of the clack valve the staging should go all over the area of the well, leaving a trap-door to descend, if necessary, to the water and galleries, if there are any such. By having the staging all over, accidents are prevented; if men slip, they cannot, at all events, fall into the water.

All the working parts—machinery, staging, ladders, etc.—*must be kept clean.* It is most objectionable to have rotten ladders, greasy, muddy staging, and dirty valve boxes in the water-raising apparatus.

The quantity of water delivered* by a pump per minute $= \cdot 00283\, d^2 l n$ where

$n =$ no. of strokes per minute.
$d =$ diameter of plunges or working barrel.
$l =$ length of stroke.

Motors for Pumps.

The motors for pumps are :—1. Manual power. 2. Animal power. 3. Steam. 4. Gas. 5. Wind. 6. Water.

1. Manual power is, of course, applicable to small quantities and

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* *The Builder*, 25th August, 1894.

lifts. It is applied either by a lever-arm, or by a wheel on the same axle as the crank shaft. Pumps worked by hand power are very useful for small detachments in forts and similar places (see *Plate* IV.).

A double-acting lift and force pump for hand power is shown on *Fig.* 24. The principle is commonly applied in fire engines.*

2. Animal power is not much used in connection with pumping engines, as the use of steam and other motors has practically superseded it. When in use the pumps are worked from a cranked shaft, which is rotated by bevelled wheels in the usual way (*vide Fig.* 25).†

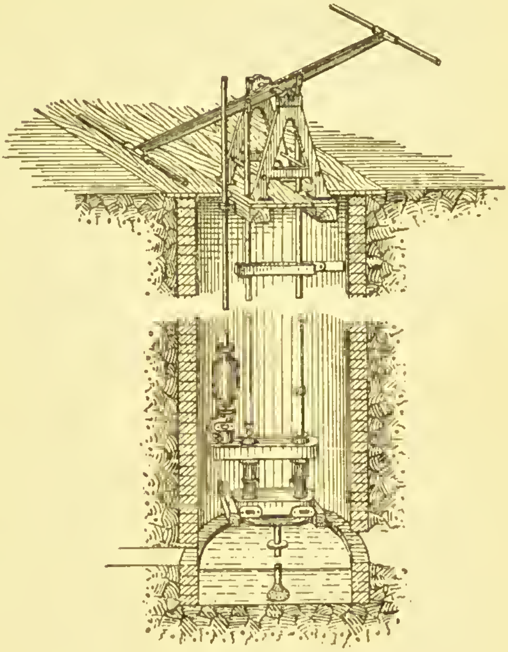

Fig 24.

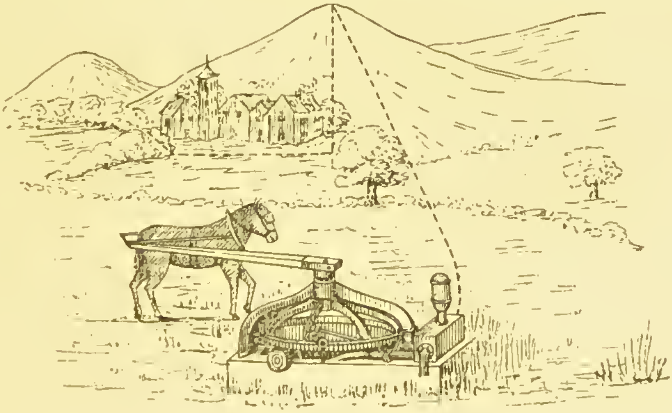

Fig. 25.

3. Steam is, of course, by far the most important motor, and a description of the various engines used ordinarily in connection with pumping machinery would take far more space than is at our disposal. Furthermore, few R.E. officers, other than those who have

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* *Vide* pamphlet by Messrs. Merryweather, *The Water Supply of Mansions.*
† *Ibid.*

had the advantages of special training in machinery, have the knowledge necessary to enable them to decide which among the many classes of engines, or of pumps, is most suitable for a given case, and as there are many well established firms who make the subject a speciality, it is generally best to put the matter in their hands, and be guided by their advice.* The engineer officer who designs the whole scheme should, however, have such a general knowledge of the subject as to enable him to state clearly what is required of the pumps, and he may then leave the details to the manufacturer. By mutual consultation on the subject a clear idea as to the whole arrangements may be worked out while the project is still in embryo. It will, obviously, be necessary to settle this early, because in many water supply schemes the pumping arrangements form an integral part of the design as a whole. Broadly speaking, there are two classes of steam engines for pumps;—(1). *High pressure*, with the least initial outlay, but greatest working expenses. They are suitable for small towns. (2). *Condensing* with greatest first cost, but highest economy of fuel and minimum strain on pipes and connections. The former class exhaust their steam direct into the air, the steam being used, as the name implies, at full pressure. Condensing engines are sub-divided into various classes—simple, compound, etc., according to the number of expansions.

The duty of a pumping engine is the weight of water it will lift one foot per unit of fuel consumed. This unit is usually fixed at 1 cwt. of coal, but is unsatisfactory owing to the variable nature of the fuel, for (as has been pointed out by Professor Burton†) even if the best Welsh coal is used, we are far from having an absolutely uniform substance. The matter is left—so far as War Department pumping machinery is concerned—very much in the hands of the Inspecting Officer of Machinery, R.E., in the district, whose duty it is to see that under the circumstances of each particular case the pumping engine is working to its best advantage.

Professor Burton, however, recommends that the duty should be stated in the lbs. of water evaporated in the boiler, and suggests

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* See Messrs. Turner and Brightmore's book, pp. 157—170, for a statement of the general principles of the various types of steam engines. A great deal of valuable information on the subject of pumps and engines can be obtained from the lectures on hydraulic machinery, delivered at the S.M.E., by Mr. Anderson in 1878, and by Mr. Rodmer in 1892, published by the R.E. Institute.

† *Water Supply of Towns*, p. 156, in a most valuable chapter on pumps, from which much information has been obtained.

10lbs. weight of water evaporated as the unit, the water being fed into the boiler at 212° Fahr. "With compound engines having working pressures of steam between the limits of about 90 and 120lbs., it is fair to expect a duty of 1,000,000 for 10lbs. With triple expansion engines, working at a pressure of 150 or 160lbs., a duty of 1,200,000 ought to be obtainable. With large centrifugal pumps, and with a head not exceeding say 25 feet, a duty of 600,000 ought to be developed. With ordinary condensing, or very small compound, a duty of not more than 400,000 to 500,000 need not be looked for; whilst small high-pressure engines of only a few horse-power need not be expected to give a duty of over perhaps one-half or one-third of this." This may be expressed by the following:—

$D = \frac{HW}{w}$ when D = duty in foot lbs.

H = height in feet to which the water is to be pumped plus frictional head in main.

W = total weight of water in lbs. pumped during any interval of time.

w = weight of water in lbs. evaporated in the boiler during the same time.

The arrangement of the buildings in a pumping station is often a matter of much importance. In designing them the following accommodation must be provided:—1. Boiler room with tall chimney. 2. Coal store. It may be convenient to provide a narrow-gauge tramway from the coal store to the boiler room to save labour in the delivery of coals. 3. Pump room over or near the well. 4. Machine shop fitted with lathe and bench for the execution of repairs. This should lead out of the pump room. 5. Office for the engineer in charge. This need not be a large room, but it should be sufficiently commodious to enable him to keep record of fuel and other stores received and issued, of the hours of working, of the quantity of water pumped, and such other matters as appertain to the economical working of the machinery. It may be well to have a weigh-bridge outside the office, with steelyard inside. 6. Small store for fittings, tools and spare gear.

A few designs are given on *Plate* VIII., which will serve as a general guide.

It is advisable to allow the makers of the pumping machinery to design the foundations for their own engines, and then adapt site to suit.

Gas.

Gas power in the case of water supply may be employed. The requisite motion is obtained by the explosion of a mixture of coal gas and air in the cylinder acting on the piston. The air next the piston combines gradually with a mixture of gas and air until the firing point is reached, and this gradual increase has a useful working effect in reducing shocks and sustaining pressure.

In Germany gas is used as a motor for pumping machinery very extensively. At Coblenz, Basel, Furth, Meissen and many other places it is exclusively employed, pumping as much as 1,000,000 gallons per diem. At Carlsruhe it is used in addition to steam power. The difficulty of supplying and carting coals to the pumping stations, and the smoke caused by the ordinary boilers, are entirely done away with by the use of gas.

Gas has further considerable advantages over steam. It can be turned on at once in case of emergency. There is no loss when the engine is not working. It is easily fixed, and requires little attention. It has been found to be much cheaper. There are further indirect advantages. Smaller water-towers may be used, as the engine supplying them can work intermittently. The gas, being required for pumping during the daytime, is at a higher pressure than at night, when it would be partly required for illuminating. Hence the gas plant is uniformly worked, and to the best advantage.

The consumption of gas per indicated horse-power varies from 17½ cubic feet per hour in the larger engines to 25 cubic feet per hour in the smaller sizes.*

Petroleum is sometimes used, on much the same principle as gas, as a motor for driving pumping engines. See *Molesworth's Pocket-Book*, edition 1893, p. 528.

Wind.

The construction of windmills for the purpose of pumping water has received much attention in America, where they are most economically used for the supply of water stations, and the type of mill used there, with many blades of comparatively small size, is now obtaining favour in England. Messrs. Merryweather and Sons, among others, have made this a special study, and *Fig.* 26, taken from their catalogue, shows an annular windmill arranged for pumping from a well 50 feet, 100 feet, or even 200 feet deep with the standard utilized as a water tank. Modern windmills of this type give excellent results, and for private supplies are most economical. The horse-power may be calculated from the following formula*:

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* *The Builder*, 11th August, 1894.

$$HP = \frac{AV^3}{1,100,000}$$

when A = total area of sails in square feet
V = velocity of wind in feet per second.

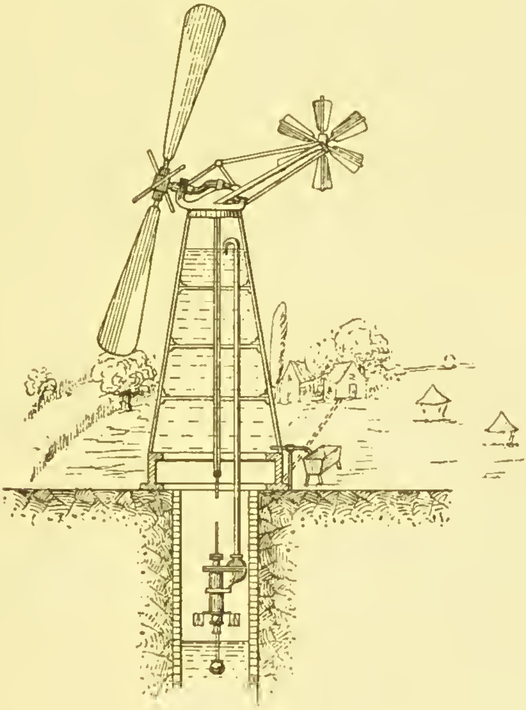

Fig. 26.

Table of Efficiency of Windmills, Working 8 Hours per Day with a Wind Velocity of 15 Miles an Hour during Pumping.

Diameter of Mill.	Revolutions per Minute.	H.P. Developed.	Quantity raised, 100 feet.
Feet.			Gallons.
12	55	$\frac{1}{4}$	3,375
15	50	$\frac{1}{3}$	5,000
18	45	$\frac{1}{2}$	10,000
20	40	$\frac{3}{4}$	12,500

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* *The Builder*, 11th August, 1894.

Table of Wind Velocity.

Velocity in feet per second	12·13	17·15	21	24.25
Velocity in miles per hour ...	8·27	11·69	14·31	16·53
Description of wind	Gentle.	Slight breeze.	Fresh breeze.	Strong breeze.

The use of wind as a motive power is, of course, subject to the disadvantage that a long period of calm may occur. Reservoirs for storage are, therefore, necessary, and these should be large enough to provide against all contingencies. In countries where there is a constant breeze, windmills would supersede all other motors for economy.*

Water.

The power of a running stream may be utilized to raise water to a considerable height. This may be applied in a variety of ways, and may be combined with *electricity*, whereby a water-wheel or turbine, actuated by the running current of water, drives a dynamo. Electricity is also used in connection with steam for pumping.

The machinery for utilizing the water power is generally simple, and the motor is, obviously, economical. *Water-wheels* are of two sorts, viz.—vertical, and horizontal or turbine. The former are of three classes, viz.—1. *Overshot*, when the water is delivered on the top of the wheel. This gives the greatest power with the least expenditure of water. This can be used when the head does not exceed 50 feet. 2. *Breast*, when the water is delivered near the centre. 3. *Undershot*, when driven from the bottom, with a strong current. This can be used when the head does not exceed 6 feet.

Horizontal wheels or turbines, upon the design of which much care and ingenuity have been expended, are very good water motors. There are many different types. For information, both practical and theoretical, on this subject, however, the reader is referred to *Molesworth's Pocket-Book*, edition 1893, p. 529 *et seq.*, and section "Hydromechanics," *Encyclopædia Britannica*, by Prof. Unwin, and the S.M.E. lectures on hydraulic machinery previously mentioned.

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* For further information on the subject of wind power see *The Windmill as a Prime Mover*, Alfred R. Wolf, John Wiley & Sons, New York. See also *Molesworth*, p. 551, edition 1893.

Of course, in all cases, by suitable gearing, the circular, vertical, or horizontal motion of the wheel or the turbine is transformed into the reciprocating motion of the piston rod of the pump, lifting and forcing the water in the ordinary manner.

Another most economical method of utilizing streams in connection with forcing or pumping water is the *hydraulic ram*. The principle of this is that if water when flowing along a pipe with considerable velocity is suddenly checked, it will cause a momentary increase of pressure on the interior of the pipe. This increase of pressure is known as *ramming*, and is utilized to force a certain proportion of the water to a height above the top of the fall pipe.

The apparatus is shown in section on *Fig.* 27.* A is the main supply pipe connected with the stream; B is the waste valve through which a considerable proportion of the water escapes; C is the delivery valve, and E the delivery pipe; D is a "snifting valve." The action of the apparatus is as follows:—The water flows down A and out at B until the momentum of the flow is sufficient to raise and close the valve at B. The sudden check given is sufficient to raise the delivery valve C, and admit a small quantity of water into the air vessel F. When the effect of the ram has subsided, the waste valve B again opens, and the same process occurs again. The object of the branch pipe at D, with its valves, is to supply the air vessel at F.

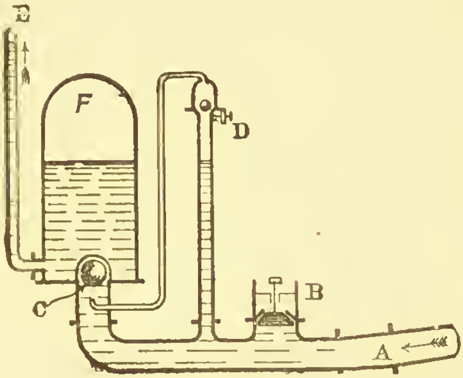

Fig. 27.

The above is a general description of the principle of hydraulic rams; further details are given in Messrs. Turner and Brightmore's *Principles of Waterworks Engineering*, pp. 154–55.

Messrs. J. Stone & Co. give the following practical information in their catalogue about hydraulic rams, one of which is shown on *Plate* IX., taken from their catalogue:—

The ram should not be fixed at a less distance than 25 feet to 50 feet from the source of supply, in order to impart a sufficient velocity to the water in the drive pipe, and thus obtain the greatest efficiency. . . . Both rams and pipes should be protected from frost. . . . A fall of 10 feet from a brook or spring is quite sufficient to raise water to any point up to 150 feet above the ram. The following table shows approximate capacities of hydraulic rams working with a fall of 10 feet and lifting to a vertical height of 50, 100, and 150 feet respectively :—

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* Taken, by permission, from Messrs. Turner & Brightmore's book.

Approximate quantity supplied by stream or spring per hour in gallons.	250.	500.	750.	1,500.	2,750.	4,500.
Approximate gallons delivered per hour, 50 feet high	35	70	105	215	390	640
Approximate gallons delivered per hour, 100 feet high	20	40	60	120	220	360
Approximate gallons delivered per hour, 150 feet high	13	26	38	80	150	240

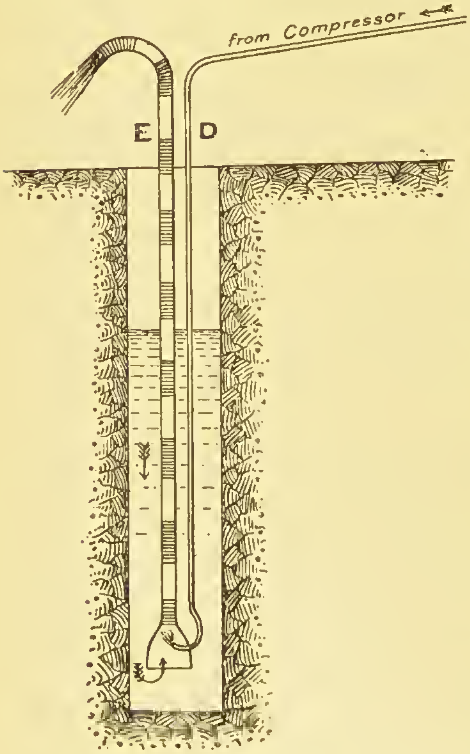

Fig. 28.

Before concluding this necessarily brief *resumé* of the various pumps and motors used in waterworks, it is necessary to say a few words about one of the most recent American inventions for raising water from deep wells, viz., the Pohlé Air Lift Pump (Alex. E. Schnee, agent, Postal Telegraph Building, New York). The apparatus shown in *Fig.* 28 consists of two parallel tubes, D and E, the former for supplying compressed air, the latter being the delivery pipe for the water. The compressed air forced down D, pushes a quantity of water up the pipe E, forming a tightly fitting piston of an elastic nature, which adapts itself to all inequalities of the bore. The water issues in a nearly continuous stream.

There are no moving parts, plungers or valves, within the pump.

All the machinery is above ground. The patentees claim that this is the most economical method of pumping deep wells, where the water-level is far below the surface of the ground. Where a number of wells are to be worked, this air lift pump finds its best field, as several can be worked from one central station.

The water is always delivered ærated, it never freezes in the discharge pipe, and the absorption of air prevents the formation of plants, etc., inside the tube.

For military purposes this pump appears to be thoroughly well adapted. It has been used largely in various forts in the United States, and the reports on its working by the officers of the Quarter-Master-General's Department in U.S. Army report on its utility most favourably. The fuel expenditure, as reported by these officers, is most economical.

CHAPTER III.

COLLECTION AND STORAGE.

Supply from Lakes.—Compensation.—Consumption per Head to be Allowed.—Gauging Streams.—Gauging large Rivers.—Supply from Large Rivers.—Drainage Areas, or Gathering Grounds.—Preliminary Investigations for Impounding Reservoirs.—Reservoir Dams.—Stone Embankments.—Earthen Embankments.—Puddle.—Construction of Embankment.

Many important water supplies, such as those for Glasgow and Manchester, are derived from natural lakes, the quantity of water in which is regulated by sluices at the outflow. Many other large communities are supplied from artificial lakes formed by the construction of dams or embankments across a valley, and ponding up the natural flow of the stream.

In all such cases in a civilized community, legal questions arise as to the compensation to be paid, or given in kind, to millowners and others having a right to the water further down. Such questions would rarely arise with regard to the supply of water to barracks or cantonments, and need not here be fully entered into. It is, perhaps, sufficient to say that the usual practice is that the Water Company must secure for the stream a quantity equal to 50 per cent. of what they themselves use for the town. This is done either by constructing a separate reservoir of definite capacity under control of the millowners, or by guaranteeing from the one main reservoir a supply of a certain amount per diem. The former method is obviously the most equitable and satisfactory.

In all cases a clear idea is necessary (1) as to the *quantity required* for consumption, and then (2) as to whether the proposed source of *supply is at all times equal to the demand.*

These principles, of course, apply equally to wells, lakes, or rivers.

In barracks the daily supply, by regulation, is 20 gallons per adult, and 10 gallons per child (*Queen's Regulations*, Sec. xv., para. 28). "This is to be taken only as a guide to the maximum rate." For horses in the cavalry, 8 gallons, and in the R.A., R.E., and A.S. Corps, 10 gallons are allowed. This is also a maximum rate. This, as the maximum daily consumption, may serve as a basis for calculation. It will, however, be evident that there will be fluctuations owing to weather. The maximum consumption may rise in one month to 30 per cent. over the mean, and the rate of consumption in any one hour may rise 50 per cent. above the mean hourly consumption. An extra allowance of 10 per cent. may be added in any scheme for fire protection, waste by leakage, and for flushing purposes. In India it is reckoned that each European requires 20, and each native 15 gallons. But owing to fluctuations above alluded to, about 3 times the actual amount should be estimated for; this can conveniently be done by estimating the delivery in 8 hours instead of 24.

Now in lakes, large rivers, and generally in deep wells, whatever the demand, calculated on the above data, may be, the minimum supply is generally sure to be in excess of it. Hence if the supply can be obtained from such sources, other things being equal, there will be less trouble experienced in the supply from these than from any other source.

In small streams and surface wells it sometimes happens that the minimum supply is less than the average demand, although the average supply may be greater than the average demand. In such cases it will be obviously necessary to impound the water in such a manner that a sufficient quantity may be available for use when the supply falls low.

To gauge a stream approximately, sufficient calculations may be made in those cases where the stream is small enough to be dammed across, so as to form a pool of some depth. In the pool a stake is driven with a mark upon it at a level a little below that to which the water will ultimately rise at the dam. Buckets of known capacity are then brought, and planks laid across so that the surface may be lowered by rapid baling out. The surface is first lowered, by baling, to a point a little below the mark, and when the water rises to the mark the time is noted. It is then rapidly baled out to any lower point, and kept at that point for some time, say an hour, the number of bucketfuls being noted. Again the surface is allowed to become still, and gradually rise to the mark, when the time is again noted. Then if Q = discharge in cubic feet per second, C = number of cubic feet removed during the noted time by the buckets, T = the number of minutes between the surface rising to the mark the first time and the second.

Then $$Q = \frac{C}{T}.$$

This method* is not applicable to a supply for more than 3,000 people, but it is extremely useful for field operations.

For streams having a greater discharge than 6 to 8 cubic feet per minute, it is advisable to use a board with a notch in it. A vertical plate placed across the stream at right angles to the flow has a wide slot, either rectangular or triangular, through which the water flows. "A water-tight weir is first made across the stream, and in this is set a frame of wood or metal, on the up-stream side of which are attached thin metal plates, forming the edges of the gauge. The latter need not be bevelled on the down-stream side, if they present a square ¼-inch edge in the vertical plane. In the common rectangular notch-gauge, three plates are used, one of them forming the sill, and the other the vertical sides of the notch. The sill is fixed level, and its length must be accurately known. The notch may be provided with moveable sides, in order that its width may be reduced when the flow is small, as it is undesirable that the height of water over it should be less than 4 inches." It is important that the plate over which the discharge takes place should be thin. A rounded edge increases the discharge. The air should have access to the space behind the sheet of falling water. "The level of the water on the down-stream side must be sufficiently below the sill—not less than one-half of the maximum depth of water flowing over it—to allow free access of atmospheric air under the discharging stream."†

On the up-stream side of the notch it is desirable to splay the sides of the channel outwards from the notch, so as to diminish the velocity of approach, and the depth of the water below the sill of the notch on that side should be at least three times the depth of water flowing over the notch. "Care should be taken to make the foundations of the weir firm, the bracing substantial, and the planking rigid, so that there shall be no vibration of the framework or crest, and its sheet piling is to go deep and well into the banks on each side, when set in a stream, so that there shall be no escape of water under or around it, and a firm apron is to be provided to receive the falling water, and to prevent undermining."‡ On the down-stream side the best preventive against destruction of the apron is a "water-cushion," or construction of the bed at such a depth below the level of the ordinary channel that the water falls into a fairly deep pool and flows down the channel in a tranquil stream. For depths, see *Molesworth's Pocket-Book* (Ed. 1893, p. 298).

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* Borrowed from *The Water Supply of Towns*, by Prof. Burton.

† *The Principles of Waterworks Engineering*, Turner and Brightmore, p. 72.

‡ *Fanning*, p. 279.

As regards estimating the quantity, if d = depth of water flowing over the sill in feet a = area of notch in square feet, $3{\cdot}3 \times a \sqrt{d}$ = the number of cubic feet per second flowing over.*

This is for a rectangular notch, and the area of the notch is the length × *depth of the overflowing water*, which should be measured several feet up from the weir, in still water, from the top of a peg exactly on a level with the sill of the notch.

A triangular notch is sometimes used instead of a rectangular one. In this case, when the sides are sloped at 45°, the discharge (in cubic feet per second) $= 2{\cdot}54\ d^{2{\cdot}5}$.

By the use of Hutchison's Patent Discharge Recorder, manufactured by the Glenfield Co., Kilmarnock, a continuous record of the quantity flowing over a notch can be gauged. This apparatus (*Fig.* 29) is based on the principle that as the quantity of discharged

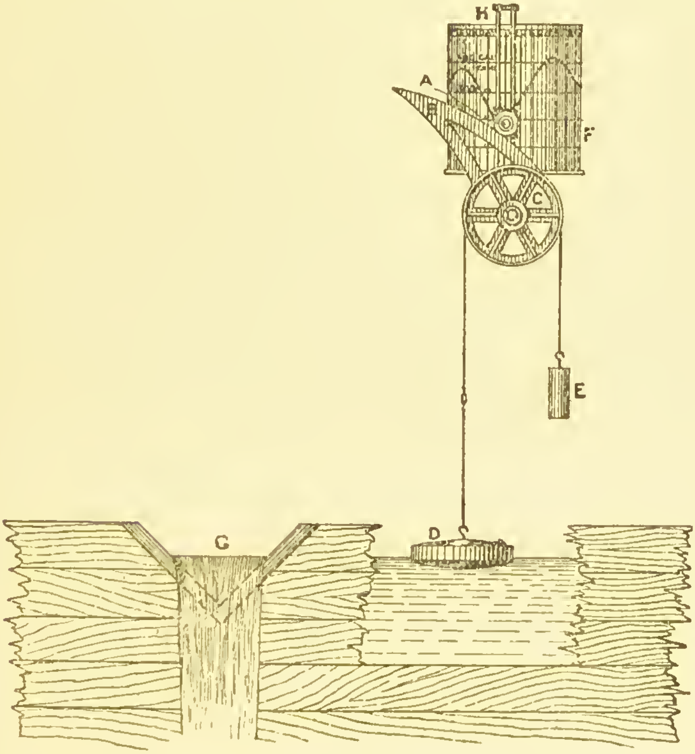

Fig. 29.

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* See *R.E. Field Service Pocket-Book*, p. 144. This is the same result as given by Messrs. Turner and Brightmore, p. 75.

water is a function of the depth, it is possible by means of a cam (B) to give a pen or pencil (A) running in guides (H) drawing a curve on a revolving drum (F) a motion proportional to the quantity discharged. The *rate* of discharge is found by scaling the ordinates of the curve thus automatically drawn, and the *amount* of discharge, in a given time, by taking the area of the corresponding figure by a planimeter or otherwise.

A " hook guage " is sometimes used in connection with the overflow from notches for the purpose of observing the height. The gauge is simply a vertical rod, with one end screwed into a frame on which there is a scale, and the other end pointed and turned up to form a hook. When it is desired to ascertain the level of the surface of the water and the corresponding level of the bottom of the notch, the hook is immersed in the water at some little distance from the notch and is raised by means of the screw until the point of the hook just touches the water surface from below. The level of the sill of the notch can then be obtained by a straight-edge levelled upon the sill and the point of the hook.*

In making arrangements necessary for these operations, it is important to bear in mind that the water above the notch must be practically quiescent.

It is convenient to remember that the number of cubic feet per minute × 9,000 = number of gallons per 24 hours.

Where the stream is too large to be gauged by the above means, a part is selected where the flow for a short distance is fairly uniform, and where the direction is fairly straight. Three or four cross sections of this portion should be taken, by stretching a rope across, with marks at regular intervals, and plumbing the depths at those marks. The mean area of the stream is thus ascertained. The surface velocity is next ascertained by taking the time necessary for a floating body to pass two marks at a given distance apart. The average time taken by a number of floating bodies should be recorded. The discharge of a stream may be obtained from surface velocity approximately.

$$Q = \cdot 84\, av,$$

where Q = cubic feet per second.
a = sectional area in feet.
v = mean surface velocity.

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* See Fanning, p. 296.

From these approximate data it is possible to estimate whether a given stream will suffice for the requirements of a given case.

LARGE RIVERS.

. Where the discharge of the river is greatly in excess of the quantity required, the problem is comparatively simple. A site would be selected which will have sufficient depth of water to give supply in the driest weather, and at a height above the point of supply to secure, if possible, sufficient flow by gravitation alone, and at such a position as would easily admit of a sufficient supply being diverted into the new artificial channel or *aqueduct* which is to connect the river with the community. The site must be at such a point that there is no tendency for silt to be deposited. Training works to ensure protection of the intake may be necessary. The head works would probably consist of a masonry regulator-chamber, with sluices, working vertically in grooves, and strainers of wire gauze to exclude floating *débris*, or fish.

It must, however, be borne in mind that all rivers hold in suspension varying quantities of solid matter, and that the water is liable more or less to the impurities caused by the population at higher points; hence there will be a greater need for filtration in the case of river water than in water supplied from mountainous districts. Thus, in the water of the Thames, which supplies London, the total impurity amounts to from 17 to 22 grains per gallon, whereas in Glasgow, where the supply is derived from the mountains round Loch Katrine, the impurities only amount to about 2⅓ to 3⅓ grains per gallon. The Glasgow water does not, therefore, require filtering at all.

The subject of purity of water and filtration will be touched upon in a later chapter; it is sufficient here to say that "in general, spring-fed streams are superior to storm-fed streams as sources of potable waters; that streams of moderate declivity or gentle (but not too slight) fall are superior to streams of high declivity; and that, other things being equal, those streams which are most completely broken up into alternating pools and rapids are preferable to streams whose profiles are more uniform."—(U.S. Geological Survey Report, 1892-3, p. 35).

The chief objection to the supply of a town situated on the banks of a river by gravitation is that either the aqueduct must necessarily be of considerable length, or else pumping has to be resorted to.

The water supply for the English settlement at Shanghai is remarkable as being taken from a tidal river at nearly full flood tide, pumped first into settling tanks (see *Plate* XXIX.), then filtered and pumped into an overhead reservoir three miles off. This reservoir, of unique design, is erected on cast-iron pillars, holds 670 tons of water, and is covered with a corrugated-iron roof.

DRAINAGE AREAS, OR GATHERING GROUND.

When the streams affording the supply are comparatively small, reservoirs are required to impound a sufficient quantity to render the supply independent of fluctuations of the weather. In such a case the engineer has to find out:—

(1). The quantity of available rainfall.
(2). A suitable drainage area.
(3). A suitable site or sites for reservoirs and dams.
(4). A suitable line of aqueduct.

All these operations, therefore, must now be considered. The conditions affecting the first have already been touched upon in Chapter I., and need not be again repeated.

As regards a suitable drainage area, it is desirable that it should be:—

(*a*). At such an elevation as to command, by gravitation, the whole of the district to be supplied.
(*b*). Open to the direction of the prevailing rain-bearing winds.
(*c*). With slopes impervious, steep, and uncultivated.
(*d*). With soil as little polluted as possible by peat-mosses, or inhabitants, either human beings or the lower animals.*

As a rule, these conditions can only be obtained in mountainous districts.

Geologically, granite and other igneous or metamorphic rocks afford the best and softest water. The old red sandstone, millstone grit, and coal measures also yield good pure water. "The new red sandstone series, in some cases, yields good water, but it is a formation very permeable, broken up by many fissures, and the water from it is subject to the generation of peculiar organic vegetable matter. Limestone districts which contain fissures should be avoided . . . and if a limestone district be selected, care must be exercised to see that the site of the works is rendered water-tight by a covering of drift or boulder clay, which is often found at the bottoms of mountain valleys, so rendering them impervious, and preserving the water in a state of softness by preventing its contact with the surface of the limestone rocks below. The dip and strike of the rocks should be noticed to see if any permeable beds occur; and if so, that they do not incline away from the drainage area, and so lead away the water. Strata arranged in a synclinal trough dipping on both sides of the valley towards the river are to be preferred; and, if possible, valleys formed by clefts along the axes of anticlinal curves should be avoided."*

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* The gathering ground at one of our home stations is a game preserve, and polluted by rabbits. The water, which is not filtered, has been condemned as unfit for drinking. Filtration would probably remove all noxious impurities.

PRELIMINARY INVESTIGATIONS FOR IMPOUNDING RESERVOIRS.

Among the preliminary investigations for selecting a suitable drainage area and reservoir site may be mentioned the following:—

(*a*). Careful observation of the rainfall on the area during one rainy season.

(*b*). Careful and frequent observation of the quantity of water that flows, during the same rainy season, down the streams. By comparing this with the rainfall, an idea of the *available* rainfall at all times may be obtained.

(*c*). A careful survey, not only of the actual site or sites, but of the contours of the impervious rock underlying the surface at those sites. For these purposes, borings or pits will be necessary.

(*d*). Materials likely to be available at the works, *e.g.*, nature of stone, lime, clay, timber, or any other substance likely to affect the cost of construction.

It cannot be too strongly impressed upon those who have to carry out the preliminary surveys and reports in such cases that time devoted to the careful investigation of the above is well spent. This is especially the case in reporting upon proposed sites of masonry dams or embankments. In these cases trial shafts should certainly be sunk, and the specimens of the material excavated carefully preserved, with a record of the work. Borings are not sufficient. The shafts should be, like a military mine shaft, large enough for the engineer to descend and personally examine the soil and strata. The trouble, expense, and danger caused by failure of the work after the water has been let in justify a most thorough preliminary investigation, and, indeed, render it absolutely necessary.

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* Binnie.

Surveys showing the whole of the drainage area and the site or sites of any proposed reservoirs should also be made. The latter should be contoured accurately at 2-foot or 3-foot intervals.

Lines and levels along and across the sites of proposed dams or embankments should also be plotted.

In acquiring the site for a reservoir, legal rights over the gathering ground should be obtained, to obviate pollution from habitations being built on what may be ultimately a picturesque locality.

In the case of large reservoirs, it is advisable to have the site very carefully examined by a geologist, unless the engineer himself has a sufficiently good knowledge of that science to carry out the work with accuracy. The presence of permeable strata dipping towards the dam, or of dislocations producing faults or fissures, are matters which cannot be too carefully examined. Several cases of failure, and enormous expense consequent on such failure, have occurred in waterworks owing to the inefficient and inadequate examination of the site, or the false economy of not making a large number of pits for geological survey.

In any case, water retained by a dam or embankment, being under very considerable head of pressure, would undoubtedly find its way out through porous fissures in the rock were the foundations not so contrived as to prevent this. The contrivances necessary for this will presently be described, both with regard to masonry dams and earth embankments. Before entering on the consideration of these points, however, it will be necessary to say something about *the considerations which affect the depth of the reservoir.*

"The mean depth of reservoirs is roughly from somewhat less than one-third of the greatest depth to somewhat less than two-thirds. If the sides of the valley slope rapidly and evenly to the stream, and the stream itself slopes rapidly, the mean depth will be at a minimum as compared with the greatest depth. If the reservoir consists of a nearly flat bottom, bounded by steep sides, the mean depths will be at maximum as compared with the greatest depth. . . . The following very useful and interesting table, the numbers in which indicate the nature of slope of sides, those with steep sides and with a flat bottom being the lower number, and *vice versa*, is taken from *Water Engineering*, by Charles Slagg:—

No.	Ratio.	No.	Ratio.	No.	Ratio.	No.	Ratio.
1	·612	20	·490	39	·452	58	·400
2	·583	21	·487	40	·450	59	·400
3	·580	22	·485	41	·450	60	·400
4	·572	23	·473	42	·447	61	·400
5	·560	24	·468	43	·435	62	·400
6	·543	25	·468	44	·431	63	·396
7	·537	26	·466	45	·427	64	·395
8	·528	27	·466	46	·422	65	·394
9	·526	28	·466	47	·420	66	·380
10	·525	29	·465	48	·420	67	·376
11	·515	30	·464	49	·420	68	·350
12	·515	31	·463	50	·420	69	·350
13	·514	32	·462	51	·420	70	·345
14	·510	33	·460	52	·420	71	·340
15	·504	34	·460	53	·417	72	·340
16	·500	35	·460	54	·407	73	·336
17	·500	36	·460	55	·407	74	·320
18	·496	37	·458	56	·405	75	·281
19	·496	38	·455	57	·400		

This table is the result of the dimensions of 75 of the reservoirs now in existence. Here ratio is mean depth ÷ maximum depth. It will be seen that the mean depth of most reservoirs is less than one-half of their maximum depth, and that the average mean depth is less than half the maximum mean depth."*

The above is a sufficiently good guide for approximate calculation. A more accurate method is to take a contoured plan of the reservoir site, measure the area of each portion contained by a contour and the dam, and multiply it by half the interval of the contours.

* Professor Burton.

Generally speaking, we endeavour to obtain a shallow, short dam, and to avoid either great depth of water or a very long dam or embankment. It is not always possible to secure a good site commanded by one such dam or embankment; sometimes two are necessary, sometimes the reservoir has to be constructed by embankments on several sides. *Plate* X., *Figs.* 1, 3, and 4, give examples of various arrangements for dams.

As valleys frequently contract a little below the confluence of two streams, such places often afford suitable sites for reservoirs. This is notably the case at the Caban Coch Dam in Radnorshire, now under construction for the Birmingham Water Supply. Here two streams join in a fairly open valley and pass through a narrow gorge with steep mountains on either side. The dam is being now (1895) built in this gorge.

Finally, as regards the number of days' supply which a reservoir should contain, the circumstances of the case must be taken into account, and the chances of a long drought. In India, two years supply should be provided. In rainy districts in England, from 120 to 140 days, and in dry districts, 200 to 300 days may be necessary.

RESERVOIR DAMS.

These are generally superior to earthen embankments when they can be founded on solid rock, and when the height is great. In most cases they are more expensive as regards first cost, but it is impossible to lay down absolute rules which will suit all cases. Nor is it intended in the necessarily limited size of this work to enter into the many important questions involved in their design.

Of recent years, many new theories have been advanced on the subject, and much scientific labour expended on the examination of the most economic form. Those who are interested in this subject are referred to the following articles or books:—

Professor Rankine, *The Engineer*, 1872; *Applied Mechanics*, 4th edition, p. 247.

Professor Kreuter (Professor of Civil Engineering in the Royal Technical Academy, Munich), in *Proceedings, Institution of Civil Engineers*, Vol. CXV., pp. 63 *et seq.*, with discussion, giving the opinions of the most prominent engineers of the present day, *e.g.*, Sir Benjamin Baker, Sir G. L. Molesworth, Professor Unwin, Mr. G. F. Deacon, and others equally notable.

Messrs. Tudsberry-Turner and Brightmore, in *The Principles of Waterworks Engineering*, pp. 208 *et seq.*

Edward Wegmann, *The Design and Construction of Masonry Dams.*

Captain F. A. Mahan, U.S. Engineers, *Study of Reservoir Walls*, translated from the French of Krantz.

Professor Ira O. Baker (University of Illinois), *A Treatise on Masonry Construction*, pp. 311 *et seq.*

There are, no doubt, other authorities, but the above will give, at all events, the theoretical researches of some of the most distinguished engineers of the present day.

It is sufficient here to say that there are broadly five conditions of security :—(1). The dam must be stable against crushing or overturning when the reservoir is full. (2). It must be equally stable when the reservoir is empty. (3). Every joint must be secure against sliding. (4). The structure must be strong enough to resist the impact of waves or thrust of ice. (5). It must be secure against the "up-lift" of water getting into the foundations or any part of the superstructure.

Generally the masonry resists the thrust of the water by the inertia of its own weight. But that thrust may be resisted by being transmitted laterally to the solid rock or artificial abutments on either side, the dam itself being curved in plan, and acting as an arch. In the latter case it is evidently possible to introduce economy into the construction by reducing the thickness of the dam. The Aqueduct Commissioners of the Quaker Bridge Dam give their opinions that such dams are suitable for deep narrow gorges if built with a short radius, *i.e.*, under 300 feet, but that if built in plan on a long curve, say over 600 feet radius, the dam would not derive any appreciable aid from the arch action, but that in case of a yielding of the masonry the curved form might prove an advantage. Further, that "the curved form adapts itself to changes of volume, due to changes of temperature."* A curved dam certainly looks stronger than a straight one, and, therefore, gives a greater sense of security to those inhabiting the valley below.

There are but three large dams of the pure arch type in the world, viz., the Zola, in France, the Bear Valley, and the Sweetwater, in California.†

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* *Vide* Colonel Sir John Ardagh's views in Appendix I.

† Turner and Brightmore.

On *Plate* XI. are shown sections of the following dams selected as recent types of such structures built in various materials :—(*a*). The Vyrnwy Dam, Wales, which is built of cyclopean rubble masonry in Portland cement. This dam permits of surplus water pouring over the top, a principle which has been followed in some recent dams in Europe, for instance, those for the Birmingham Water Supply. (*b*). The Quaker Bridge Dam, U.S. (*c*). Tansa Dam, Bombay Waterworks, built in rubble masonry, in hydraulic lime. (*d*). The Tytam Dam, Hong Kong, built of concrete. (*e*). The Betaloo Dam, Australia, built also of concrete. These examples, taken from various parts of the world, will serve as a guide to military engineers having to design such structures. Dams of lower heights can be adopted from these forms. The factors which determine the form of the section are the depth of the water, and the nature of the material of the dam. Professor Kreuter's proposed section* is also given as a sample of the most recent theory on the subject, and the Caban Coch Dam as the most recent English practice.

As regards the width at the top, it is usually sufficient to give such as will enable the dam to serve as a roadway across the valley. At Vyrnwy the road is carried on a series of arches through which overflow water flows. Where a road is not required, the minimum width is variously stated by authorities at from 5 to 6·5 feet for small reservoirs to 14 or 16 for very large ones. The top must be wide enough to resist the wash of waves, or the thrust of ice in cold countries.

By far the greater number of failures in dams occur from defects in the foundations. All the principles, therefore, that apply to the foundations of other structures apply with greater force to masonry dams, and no pains should be spared to secure the best possible foundation. It would not be prudent to build a dam on anything but a continuous rock bed throughout. The rock bed should be cleared of surface rock, which is often disintegrated and unreliable ; if it is sloping it should be stepped, and dovetail joggles cut in the rock to give a key to the masonry or concrete. Any fissures in the rock must be filled in with good cement concrete, generally forced in under pressure. As the dam will have to resist both a horizontal and a vertical pressure, the bonding must be carefully attended to. Uncoursed rubble is generally employed. The joints on the faces should be as thin as possible, and all voids thoroughly filled in with the best mortar. Professor Baker * recommends that the water face should be treated with Sylvester's process (*i.e.*, Castile soap and water, and then alum and water), so as to render the masonry waterproof.

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* This is not quite accurately drawn in the plate, but it is difficult to do so on such a small scale.

As a rule, the masonry is homogeneous, *i.e.*, wholly of one sort of stone, or of concrete. In some cases this is not so. *Fig.* 30 shows a section of a dam near Chemnitz, in Germany, which is built partly of concrete, and partly of different sorts of stone. The curved form of the base is worthy of note.

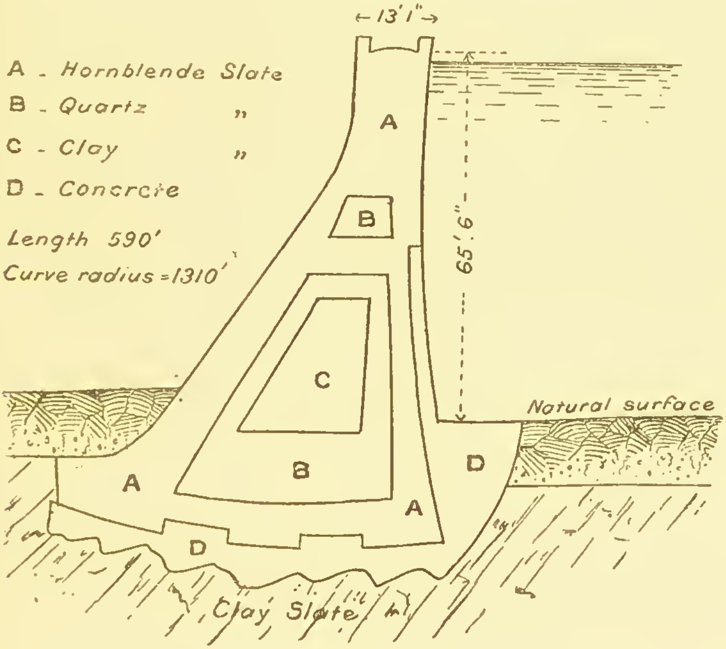

Fig. 30.

The failure of the dam at Bouzey in France in April, 1895, has attracted much attention and is very instructive. This subject is treated in a report published in Appendix I.

STONE EMBANKMENTS.

Where stone is very abundant, an embankment may be made of irregular masses, or rocks, packed together, called in America *Rock Fill* dams. These are thus described by Prof. Baker :—" The dam may be made practically watertight (1) by filling the voids with smaller stones, gravel, sand, or earth, or (2) by placing any desired thickness of earth and puddle on the up-stream face, or (3) by covering the water slope with one or more thicknesses of planking, which is calked, and sometimes also pointed."

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* Treatise on *Masonry Construction*, p. 333.

One of the largest of such dams has been made with a top width 10 feet, water slope 20 feet horizontal to 47 feet vertical, back slope 70 feet horizontal to 180 vertical, and total height 110 feet.

Such a structure is suitable when leakage is of no importance, "where skilled labour is scarce and costly, and where simplicity of work rather than aggregate quantities is the important consideration, where good materials for masonry are scarce or absent, and where the surroundings do not demand attention to the question of appearance."

Such a description of circumstances applies with accuracy to the condition of affairs in many of our frontier posts in India. It is evident that "rock fill" dams are well worthy of our attention. They have many advantages to recommend them. They are always in stable equilibrium, they tend to improve with time, they cannot be injured by burrowing animals, and if constructed with common sense and fairly reasonable care in the supervision, can be put together by the roughest of artisans.

The bed on which such structures are built should be impervious, and not liable to be under-scoured.

This form of dam has been very largely used in the Western States of America, and the work is said to be 50 per cent. cheaper than earthen dams of equal cross-section.

EARTHEN EMBANKMENTS.

When the depth of the water to be retained is less than 80 feet, or where it is not possible to obtain a rock foundation, earthen embankments are generally used. As compared with masonry dams, however, they have many disadvantages, they are much more liable to leak, are treacherous when filled, inasmuch as they may give way without warning, are liable to deterioration from waves and from burrowing of animals, and are troublesome to construct.

The interior of the embankment should be formed of puddle—this is called the "puddle core," or puddle wall.

To prevent the percolation of water beneath the embankment, the puddle core is carried down vertically to an impervious stratum.

below, sometimes to great depths. The excavation for this is called the "puddle trench."

This must extend on both sides of the valley to a point above top water level, *where it should tie into some water-tight stratum.*

"Its width will depend upon the height of the embankment and the thickness of the puddle wall, to the thickness of which at the ground level it should always be equal; sometimes it is decreased in width as it becomes deeper," but it is better to construct the sides vertical (see *Plate* XII., *Fig.* 2).

In older rocks all the depth necessary will be to carry the trench below surface fissures into the compact rock below. In such cases it is well to remember to protect the flanks of the trench so as to obviate the chance of water finding its way round.

In stratified rocks greater care must be taken, owing to the existence in many formations of water-bearing fissures.

In all cases, while care must be observed to guard against all possible contingencies, the amount of depth must be in proportion to the work required. Very shallow reservoirs, such as many of the native tanks in India, require no puddle core at all, being sufficiently consolidated by the passage of many feet bringing baskets of earth laid, and rammed in layers. Such embankments, however, are more liable to failure than those constructed with puddle, and it is noteworthy that they are seldom used for a depth of water exceeding 40 feet.

In the construction of a puddle trench, the bottom should not be stepped longitudinally, because the sudden unequal strains at the steps cause vertical cracks in the puddle. Hence the better practice is to avoid abrupt changes of depth in the puddle by forming the bottom of the trench in long slopes, gradually changing the depth.

During the excavation of the puddle trench, springs may be tapped, and difficulty caused by water flowing into the trench down the sides. To obviate this, special pipes have been designed (and used at the Leeds Waterworks) made of cast iron, and laid in concrete, as shown on *Fig.* 31. The water finds its way into these pipes through the openings at the top, and is led away to a sump, whence it can be pumped out. If a flood down the valley is anticipated, it is well to stop pumping, let the trench partly fill with water, and then if flood-water does overflow the top, it will fall on a water cushion and do comparatively little damage. It can be pumped out afterwards.

It need scarcely be said that where deep puddle trenches are constructed, very careful arrangements must be made for shoring.

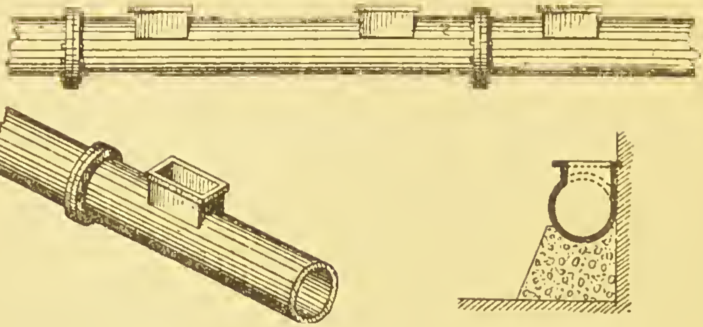
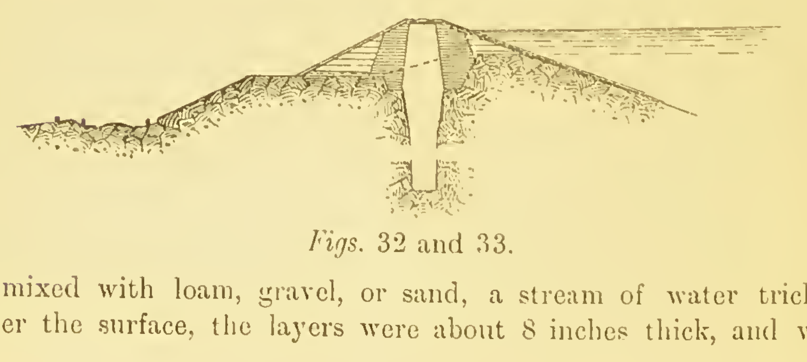


Fig. 31.

PUDDLE.

It may, however, be enquired what is the best material for puddle, and how should that material be applied ? On this subject there is a great difference of opinion. Some engineers hold that pure clay is the best material, and all that is necessary is to allow sufficient water to mix with it to render the whole a homogeneous mass. Others hold that the puddle should be carefully trampled, and one layer incorporated with the one below by close, deep cross cutting. In the great Craigmaddie reservoir, near Glasgow, sections of which are shown on *Figs.* 32 and 33, the clay used in puddle was quite unmixed with loam, gravel, or sand, a stream of water trickled over the surface, the layers were about 8 inches thick, and were



Figs. 32 and 33.

cut up in longitudinal and transverse spade-lines, so as to divide the area into squares about 6 inches or 8 inches each way. The workmen did not trample through the mass, but did their work from planks laid on the surface.

In India the clay used in puddle is pure, the workmen there use no tool, but trample the mass, mixed with water, up and down with their bare feet, until the whole is thoroughly plastic; thus they can detect any twigs, roots, etc., in the clay, which should be removed.

On the other hand, many eminent men consider that very strong clays are unsuitable because of their disposition to shrink and crack when dry, and prefer a lightish loam with a mixture of coarse sand or very fine gravel.

Anything in the shape of top soil must be carefully excluded on account of the roots and vegetable matter which it may contain. The failure of a service reservoir at the Curragh Camp, in 1888-9, was probably due to the quantity of vegetable matter in the soil used for the puddle.

One advantage of the sand or fine gravel is that the coarser particles tend to close up any tiny leak through which water may be flowing. Gravelly earth is considered by Mr. Trautwine* to be the best material for reservoir embankments.

The following are notes† on the varieties of clay, and their distinguishing qualities for making good puddle.

Most clays, when free from coarse gritty impurities, contain sufficient alumina to become practically impervious to water when worked up into puddle. When puddle is protected from evaporation, as is generally the case, the admixture of impurities has the disadvantage of diminishing its cohesiveness, and consequently its impermeability. If, however, puddle is placed so near the surface as to be liable to lose its moisture by evaporation or capillary attraction during dry weather, the addition of sand may be necessary to prevent the contraction of the mass, and the consequent formation of fissures such as occur in clay soils in time of drought. The sand, by diminishing the cohesiveness of the clay, obviates the rupture produced by the contraction of a tenacious mass; and with this object the brickmaker adds sand to clays deficient in silica to prevent his bricks cracking when being burnt, and the potter incorporates ground flint with his clay to reduce the amount of contraction.

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* *Civil Engineers' Pocket-Book*, p. 287. Ed. 1893.

† *Minutes of Proceedings, Institution of Civil Engineers*, Vol. XCIV., 1888, paper by W. Galton, A.M.I.C.E.

The general suitability of most kinds of clay for puddle has caused an absence of precision in the definition of the requirements for puddle in specifications. The essential condition for puddle is that it must be impervious to water, and no special purity in the clay is required to attain this result. Tempering the clay by working it up with water, so that its original formation is broken up and a new arrangement of particles formed, with additional water to fill up every pore, is the important requisite for the formation of good puddle. It is peculiar that puddle, though formed to exclude water, should require water for its manufacture. Tempering clay to form puddle is greatly facilitated by exposing the material to the atmosphere, especially in winter, when rain, snow, frost, and changes of temperature disintegrate the clay more thoroughly than even grinding it in a pug mill; and the labour of working it into puddle by cutting, cross-cutting, poaching it with a tool, or treading, is materially reduced. Clays well suited for puddle are opaque and not crystallized; they exhibit a dull, earthy fracture; exhale, when breathed upon, a peculiar faint smell termed argillaceous; are unctuous to the touch; free from all gritty matter, and form a plastic paste with water.

The important properties of clay for making good puddle are its tenacity or cohesion, and its power of retaining water, which really co-exist, but are separated to facilitate description. The tenacity of a clay may be tested by working up a small quantity with water into a thoroughly plastic condition, and forming it by hand into a roll about 1 to 1½ inches in diameter by 10 to 12 inches in length. If such a roll is sufficiently cohesive not to break on being suspended by one end when wet, the tenacity of the material is ample. To test its power of retaining water, 1 to 2 cubic yards of clay should be worked with water, by the usual methods, to a compact homogeneous plastic condition; and then a hollow should be formed in the centre of the mass capable of holding four or five gallons of water. After filling the hollow with water it should be covered over to prevent evaporation, and left for about 24 hours, when its capability of retaining water would indicate its suitability or unsuitability for making puddle.

When a puddle trench has been dug to its proper depth, the clay or other stuff should be thrown in, or lowered in skips if the depth is considerable, and water ladled on with a scoop or sprinkled from a hose. If the stuff be stiff it may then be left for two or three hours, adding more water if necessary. Then the puddler, who should either be bare-legged or be provided with long boots, begins at one end of the trench, and keeps chopping with his spade (curved like a cheese scoop is a better form than a straight spade), giving it a lunging move every time he withdraws it, so as to let the water into the puddling stuff and permeate it throughout. If more water be wanted another man supplies this as the puddler works on. He goes on chopping and trampling over every inch of the ground as he works down the trench till he gets to the end; then he returns and repeats the operation till the stuff is worked thoroughly up. When the tool passes with equal ease through every part of the stuff (which it will not do if there are hard dry lumps) the work is sufficiently done.

A proper supply of water is very essential to this work, and it may often be wise to make special arrangements both for bringing water in ample quantity to the site of the work, as well as for draining off any surplus.

When the first course has become fairly solid, the second course of stuff, not thicker than 10 inches (and some engineers consider 6 inches a maximum), may be laid on. Water is then applied and the puddling recommenced, care being taken that the tool at every cut sinks through the upper to the lower layer, so as to bond them together.

As puddle is liable to contract if exposed to the heat of the sun, it must be protected. It will be more liable to contraction if much water has been used in working it.

Some engineers of experience consider that instead of bringing the stuff in its natural state to the site of the work, there to be worked up into puddle, it is better to prepare it by tempering, cross-cutting, watering, etc., at the place where it is dug, and afterwards transport it to the site of the work, where it is spread in layers and incorporated with existing work. Much will necessarily depend on the experience of the labourers (and in all cases it is wise to employ men who have had previous experience of this work), but the method of preparing the stuff first, and then transporting it, has the advantage of securing a frequent kneading and turning over of the stuff, and also the danger of using too much water, and thus producing a mass of semi-fluid mud, is lessened.

In the large service reservoirs of the West Middlesex Waterworks, formed wholly in porous gravel, a puddled bed 3 feet thick was formed all over the base, and continued in the core of the earthen sides, as shown in *Fig.* 34.

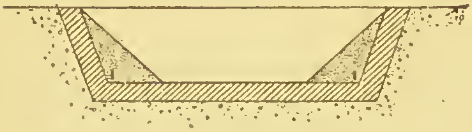

Fig. 34.

It is sometimes an advantage to allow the clay for the puddle to be cut, weathered, and worked up in pug mills, as if it were required for brick manufacture.

In the construction of puddle trenches in large works it is sometimes advisable to divide the puddle into sections distinct from one another, by cross walls of brickwork or concrete. This tends to strengthen the puddle core, and with it the embankment, and lessens the risk of sudden failure. There is, however, the danger of water creeping past the junction of the wall and the puddle. To reduce this risk, the surfaces in contact are broken up with indentations.

On *Plate* XII., *Figs.* 1 to 4, are shown various methods of dealing with the bottoms of puddle trenches by constructing longitudinal walls of concrete or brickwork in cement, the object being to avoid any risk of the puddle being cut through by water passing under it at its junction with the natural ground. In fissured rock it is advisable to line the whole of the down-stream side of the trench with concrete to prevent puddle being squeezed into the fissures, as in *Plate* XII., *Fig.* 4. *Fig.* 5 gives a geological section along a typical case showing the base of the concrete.

Often the trench is entirely filled with concrete, puddle being used only in the core of the embankment (see *Plate* XIII.).* Concrete is, of course, much stronger than puddle, it may, therefore, be made of less thickness, sufficient, however, to ensure its being perfectly water-tight. "As a matter of cost, much will depend upon the possibility of procuring suitable materials and the price of hydraulic lime or cement, but as a very much less thickness is required, a saving is effected, not only in the material of the filling, but also in the excavation of the trench. Near the surface of the ground where the junction is made between the concrete filling of the trench and the foot of the puddle wall in the embankment, it is usual to spread the concrete out to the full width of the puddle wall, and bring up concrete walls at the side (see *Plate* XIII.) to protect the point of junction ; a tongue wall of concrete can also be carried up into the puddle on the centre line of the puddle wall, and immediately over the concrete filling of the trench below."*

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* An experienced engineer said to the writer: "I never use puddle if I can get anything better; it is generally cheaper in the end to use concrete."

CONSTRUCTION OF EMBANKMENT.

The first operation in the formation of the embankment (which will go on simultaneously with the excavation of the puddle or concrete trench) will be to remove from the site on which the embankment is to rest all surface vegetable soil for a foot or so, as well as any other material of a peaty, slippery, or compressible nature, and also any silt or earth which when acted on by water is likely to become quick-sand. It may be desirable in the case of porous soils to take a sheet of puddle under the inner half of the embankment from the core. The outer part of the embankment should rest on ground that is thoroughly drained, so that it may not be liable to saturation from moisture. Inasmuch as there will be generally a downward slope longitudinally in the natural surface at the outer part, it will become liable to slip if saturated with water and on slippery soil. Hence subsoil draining here is of great importance. If the natural slope is great, it may be further necessary to step the base of the embankment as in *Fig.* 35, and in many cases the embankment bed is cut in long indentations so as to prevent settlement (see *Plate* XIII.)

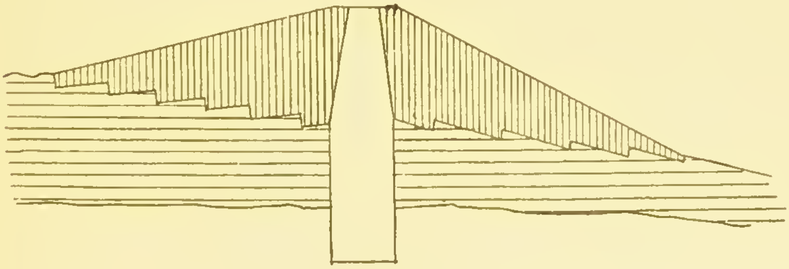

Fig. 35.

The actual embankment itself (apart from the accessories which will be considered hereafter) consists of:—1. Puddle or concrete core. 2. Filling in of selected material. 3. Filling in of the main body of the dam. 4. Stone pitching on the inner face. 5. Turfing the exposed slopes and top.

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* Binnie.

The puddle or concrete core is a continuation upwards of the puddle or concrete trench. Sometimes concrete is used for the trench and puddle for the core. The width of the puddle core at the ground should be about one-third of the depth of the water it has to sustain, and the top width varies from 5 feet to 10 feet. In very deep reservoirs these dimensions may be increased. Another rule is to make the top width 5 or 6 feet, and give a batter on each side of 1 inch for every foot in height. The puddle should be brought up concurrently with the rest of the dam, and laid in thin horizontal layers. As regards the design of the embankment, the almost universal practice in England is to make the inside slopes 3 to 1, and the outside slopes 2 to 1. American practice slightly differs from this in some cases. *Fig.* 36 represents a cross-section of a dam at the Boston Waterworks. In that case the core wall is of concrete, plastered with Portland cement.

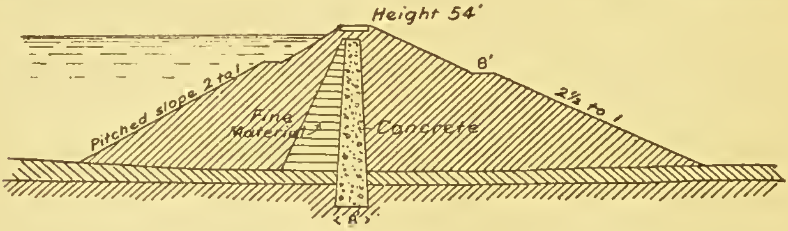

Fig. 36.

In well constructed works there is no sudden change from material of one kind to others possessing qualities of another description; hence the puddle wall should be supported on either side by clay backing, well rammed, trodden and watered (see *Plate* XIII.). This is not so plastic as puddle, but is more solid and homogeneous than the ordinary earth. The thickness may be about 5 feet or 6 feet. Next to the clay is selected earth of as uniform a consistency as possible, and of a clayey and retentive nature. Its thickness at all points, measured from the outside of the puddle wall, should equal the height of the embankment.

Outside this selected earth the harder, rougher, and less water-tight material is laid, all slippery clay, etc., being excluded from it, so that the outside slopes of the embankment may preserve their original inclination.

The general character of the cross section is :—"Steep near the top, gradually becoming flatter down to a point about two-thirds the total height, after which it again becomes steeper, and often terminates very abruptly." (See *Plate* XIII. for typical section).

On the outside additional precautions to prevent slipping must be taken; the base of the bank should be thoroughly drained, and all the harder, more rocky, and stony material placed on the outer part of the bank. The slopes may be broken up by terraces or berms, which are sometimes useful for roads crossing the valley at different elevations.

The height of the top of the embankment should be not less than 5 feet above highest water-mark, but it may be more in cases where the "fetch" or open reach of water open to the winds is very great. Sometimes the slope above the water-line is made steeper than the rest of the embankment, and is finished off at the top with a dry rubble wall (see *Fig.* 37), or with an ashlar coping as in *Fig.* 38.

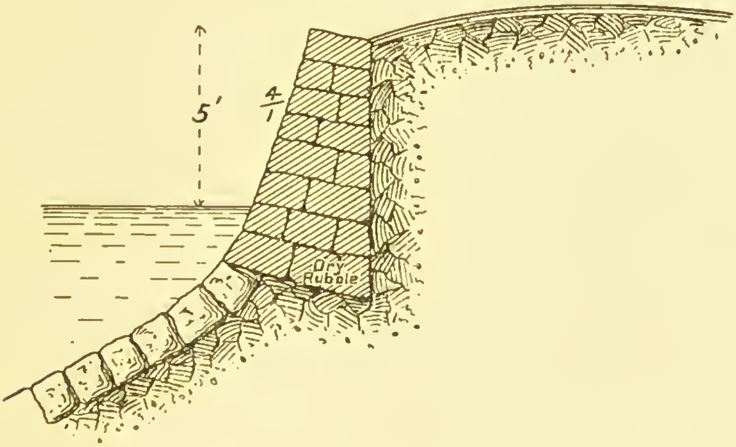

Fig. 37.

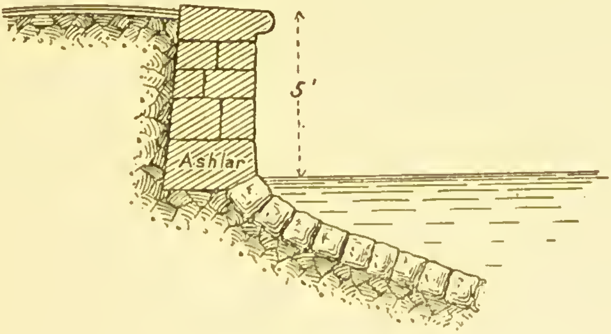

Fig. 38.

The top width is from 8 to 20 feet, and is usually about 12 to 16.

It is generally made about one-third of the height. The inner slope should be protected with stone pitching throughout; this should be put on when the bank has become consolidated, and a stratum of broken stones or quarry rubbish should underlie the pitching. Some authorities recommend that the toe of the pitching should be embedded in a concrete footing. The depth of stone pitching should be 12 to 18 inches.

Concrete blocks of uniform size give good results. Possibly hexagonal-shaped blocks would make a better job than square or rectangular.

Puddling the inner slope is not recommended. It has often been tried so as to serve the double purpose of protecting the slope and making the bank water-tight, in preference to a puddle core; but it has frequently proved to be a failure, or involved heavy cost in maintenance.

In "rock fill" dams the slope is sometimes protected with 3-inch planks bolted horizontally to anchorage in the stonework.

The whole of the embankment should be constructed in layers of from 9 inches to 2 feet in thickness, or as thin as possible consistent with economy of construction. *No high tips, as on railways, can be allowed.* Each layer must be continuous. It should dip towards the puddle wall on each side, and when complete should be consolidated by rolling.

"To provide against the possibility of high tips, and to secure thin layers and uniform distribution, some engineers specify that no earth wagons shall be allowed on the embankment; . . . however, if the layers be kept down to a maximum of 30 inches in thickness, the continual passage of the heavily laden wagons, followed as it should be by heavy rollers, will be found to have a beneficial effect rather than otherwise. The presence of stones or rocks in the earthwork of an embankment must not be understood as prejudicial to its stability, but only when they occur in strata or continuous layers, for there can be no doubt that when they are isolated from each other, and surrounded by good earth, they tend to give it weight and solidity, and this is specially the case in the outer parts of the work where their presence, especially in the outer parts of the outer slope, should be provided for."*

One of the most remarkable embankments which the writer has had the privilege of visiting when under construction is that at

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* Binnie.

Jeypore in Rajputana (Colonel S. Jacob, executive engineer). The height of this dam (which is fully described in *Min. Proc. Inst. C.E.*, Vol. CXV.) is 61 feet, length 680 feet, width at top 30 feet, at bottom 390 feet. The material is *sand resting on sand*, and the site of the works is at a point in the Amani Shah river where the banks are precipitous. The work was speedily executed so as to be ready in one working season, and the success of the whole was doubtless due to the extreme care taken to consolidate each layer, which was not only rammed in the usual way, but every day a number of the Maharajah's elephants were turned on to walk over it. Outside the toe of the outer slope, where leakage often occurs, Colonel Jacob first laid a layer of sharp sand about 10 feet wide and 6 feet deep, then a similar layer of small broken stone, and lastly a similar mass of large rubble along the whole length. It was fully expected that there would be some leakage, but that this would keep the embankment secure. There was less leakage than was anticipated.

In this case, and it may be in many others in similar circumstances, both in waterworks and irrigation, the bank is constructed so as to provide for the safe passage of any leakage from the inside to the outside without carrying away any of the material of the bank. In course of time, when the stream has brought down with it a quantity of sediment, the bank will become more and more water-tight, and, like the "rock fill" dams, will always be improving. The dimensions, however, of the Jeypore dam show that, to begin with, a large mass must be opposed to the pressure of the water, and that mass must be as homogeneous as artificial means of ramming can possibly make it.

In the Cantreff reservoirs for the water supply of Cardiff, the inner toe of the embankment, *i.e.*, on the up-stream side, is made of carefully packed stone. The engineer (Mr. J. A. B. Williams, M.Inst.C.E.) considers that a wedge of stone at that part of the embankment tends to prevent leakage and assists stability (see note on *Plate* XIII.).

CHAPTER IV.

RESERVOIR ACCESSORIES.

Residuum Lodge or Settling Tanks.—Bye Channels.—Waste Weir.—Outlets.—Valve Wells.—Valve Towers.—Syphons.—Tunnel Outlets.

In every reservoir, whether impounded by a masonry dam or earthen embankment, there are certain accessories, some of which are in certain cases desirable, some in every case indispensable.

The first of these is what is called a *residuum lodge*, or small settling tank situated at the upper end of the reservoir. The object of this is to allow the silt and other coarse substances to be deposited before the water flows into the reservoir. These tanks are provided with sluices or pipes for emptying them; sometimes they are in a series, so arranged that one may be emptied and cleaned while others are in use. *Plate* XIV. shows one which is arranged with a series of pools below it, and it will be at once seen that the effect of these pools is to cause a deposit of silt in each successively.

In connection with these settling tanks it is customary to provide a permanent *bye channel* to divert and pass off from the reservoir the storm or flood water brought down in floods, water which is probably discoloured, and, therefore, not suitable for drinking purposes. Sometimes "separating" or "leaping" weirs are arranged, as in *Plate* XV., to allow turbid water to pass away from the reservoir in time of flood. An adjustable separating weir is shown in *Fig.* 39 (taken from the Glenfield Co.'s catalogue by permission).

The position of the bye channels is shown on *Plate* XIV.* It will be seen that these channels skirt the margin of the reservoir at a contour slightly above high water mark, and discharge into the valley below the embankment.

The design both of the settling tanks and of the bye channel will vary with circumstances. As a rule, if the velocity of flow is great, it is well to make the whole, tanks and channel, of masonry or concrete. But in many cases this is not considered necessary.

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* From Mr. Binnie's lectures.

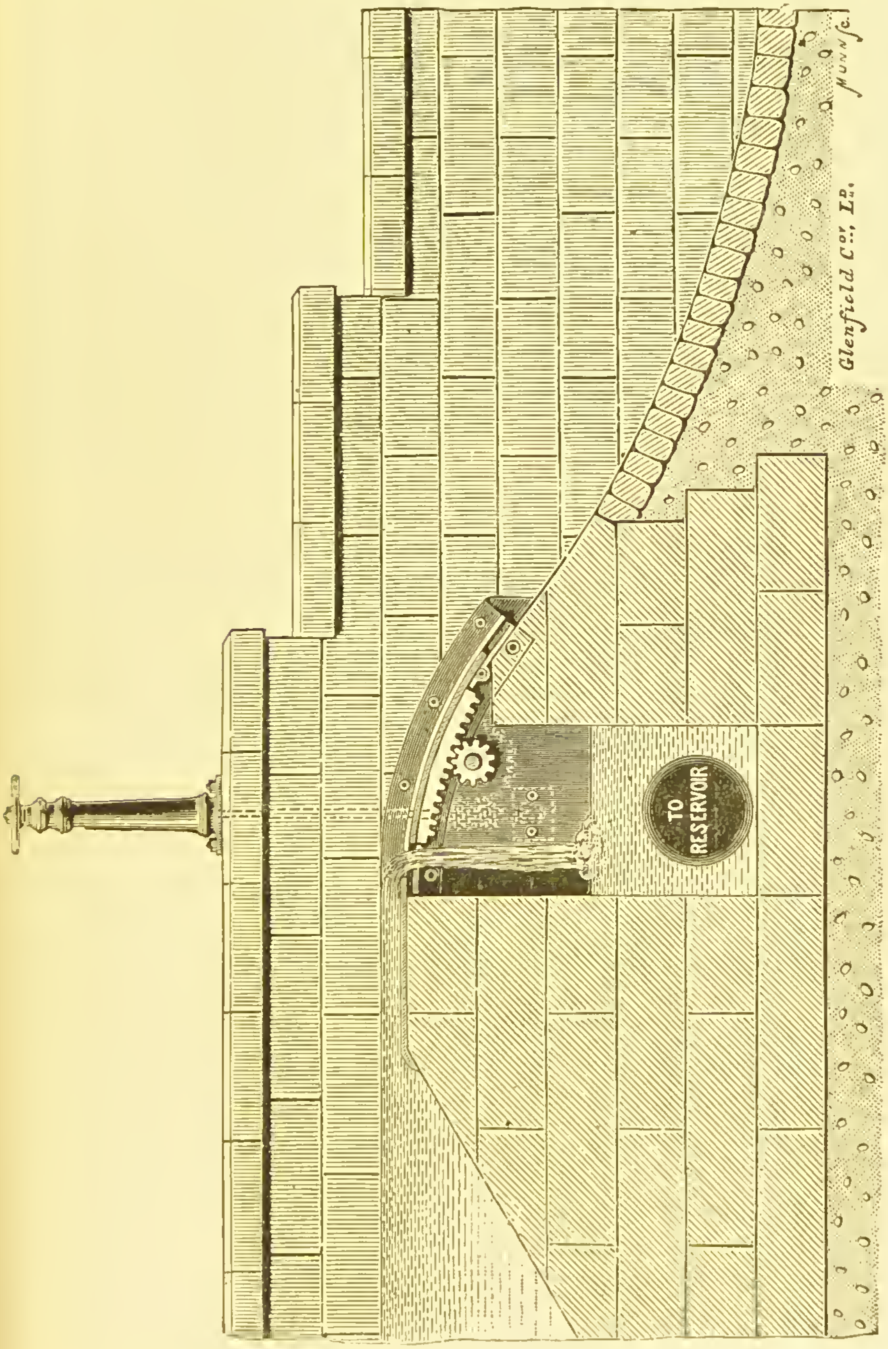

Fig. 39.

During the construction of a reservoir it is, of course, absolutely necessary that the work should be protected from sudden floods. The bye channel is, therefore, one of the first works that must be undertaken, unless, as is sometimes done, the tunnel outlet to the reservoir is made of a sufficient size to take off the whole of the heaviest flood. In such a case the outlet may be made first, the stream diverted to flow through it, and the work of the reservoir carried out. But the construction of a tunnel is often a slow affair, and the disposal of the river water through the tunnel sometimes a very difficult matter ; hence the construction of a bye channel is, as a precautionary measure, most important. The disposal of the valley water is one of the most troublesome problems, often, in connection with the whole work. If the sides of the valley are steep it may be impossible to construct a bye channel except at prohibitive cost. Frequently a culvert is constructed in the dam, and closed at the last by a special gate or shield, which is then, as soon as possible, built in from behind.

WASTE WEIR AND WATERCOURSE.

At the lower end the bye channel discharges into the *waste watercourse* or bye wash—an artificial masonry channel made on the side of the valley near its point of junction with the reservoir dam or embankment (see *Plates* XVI. and XVIII.) Into this the surplus water of the reservoir also, in most cases, discharges over the *waste weir*. The two works of waste weir and watercourse are thus inseparably connected, and we shall, therefore, consider them together

In some reservoirs the waste water pours over the top of the dam throughout its length. This is the case in the Vyrnwy reservoir. In the case of "rock fill" dams, the water filters through the structure; hence a waste watercourse is unnecessary. But in the great majority of cases the waste weir and watercourse or bye wash, are among the most important accessories of an embankment.

Even in cases where, as at Vyrnwy, it would be possible to pass the surplus water over the dam, the quantity may be so great and the height of fall so considerable as to render it inadvisable to allow the foundations of the work to be subject to the shock of a large quantity of water falling. Thus at the Tansa dam (see *Plate* XI.) the flood water was allowed to pass over the top of the masonry during the first three seasons of construction, the depth of the water over the crest being sometimes as much as 6 feet. Incidentally it may be mentioned that although the work was left rough, not a stone was ever displaced by this quantity of water passing over it.

After the dam reached a height of 50 feet, however, it was considered advisable to construct a waste weir by leaving a definite portion of the dam at one end of a lower height than the rest.

The waste weir, being the safety-valve of the reservoir, demands much attention, both in design, details of construction, and subsequent maintenance. The dimensions* are determined by (1) the maximum flood discharge, and (2) the depth of water which it is permissible to pass over the crest of the weir. This depth is generally limited to 2 feet as a maximum (Mr. Binnie says 1 foot to 18 inches). The edge of the weir will give the normal top level of the reservoir. If the water rises much above this, waves blown by strong winds may come on to the top of the embankment. *Fig.* 40 shows a waste weir where the steps are arranged so as to increase in width, and diminish in height as they go down. This is an American system and is suggested by Mr. Fanning. The edges of the steps are on a parabolic curve.

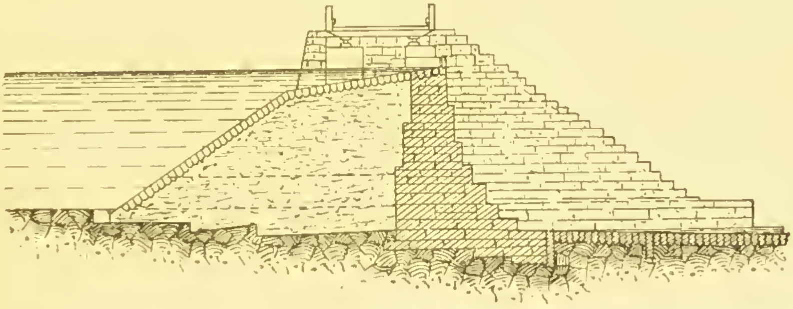

Fig. 40.

The length of the weir may be ascertained from the formula $l = \frac{Q}{8}$, where l = the length of the waste weir in feet, and Q = the maximum flood discharge of the catchment area in cubic feet per second.

An approximate length, based on considerations of rainfall, is

$$l = 2\, R_m\, A^{\frac{1}{2}},$$

where R_m = mean rainfall in inches, and A = number of thousands of acres in the catchment area. Another rule is

$$l = 20\, A^{\frac{1}{2}},$$

where A = area of water basin in square miles.

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* Turner and Brightmore, p. 205.

In arranging the plan of a weir, it is always best to place it at right angles to the direction of approaching current, because it is no only the shortest and cheapest length that can be adopted, but also the current is equally concentrated throughout the entire length.

Where there is *any* doubt as to the maximum discharging capacity of the catchment area, arrangements may be prudently made to design the weir so as to be capable of future extension. By observing the depth of water flowing over the crest during the first heavy flood, one may get an idea as to whether the dimensions given are sufficient or not.* A rough rule sometimes adopted for lengths of waste weirs is 3 to 4 feet of length to every 100 acres of drainage area. Mr. Fanning, however, says this rule is only applicable up to 3 or 4 square miles.

The subject is of such vital importance that it may be well to investigate it a little further. From recorded floods in England the maximum is 600 cubic feet per second per 1,000 acres. Assuming that the length of the waste weir was 40 feet, *i.e.*, 4 feet for every 100 acres, we should then be able to calculate the depth of the overflow from the formula $Q = 3{\cdot}3 \times a \sqrt{d}$. In this case $d = 2{\cdot}75$ feet, which is an excessive depth.

Now if this is the case in England, where the maximum recorded rainfall in 24 hours is 6 inches, and slopes are not very great, the depth would be, *à fortiori*, excessive in a tropical mountainous country with a rainfall of 4 or 5 inches per hour.

Such a rainfall may produce floods of 1,000 to 1,500 cubic feet per second per 1,000 acres, according to the geological character, slope, and degree of saturation of the soil;† hence it would be necessary, if we limit the depth of water over the weir to 2 feet, to give a length of from 11 to 16 feet per 100 acres. Flood intensity decreases as the size of the drainage area increases, hence this extra length is of more importance, relatively, in small reservoirs than in large.

Clearly it is most essential to give the maximum dimensions to a waste weir. Sudden and heavy storms are not so rare as we sometimes think.

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* The writer's experience of flood discharges on the Indian frontier leads him to the conclusion that most drainage works are designed too small. The possibility of future extension is rarely contemplated. In the case of reservoirs, the risk of a failure is far too serious to be compared with the extra expense of allowing extra "spillway" accommodation.

† At the Tansa dam the heaviest floods were over 1,000 feet per second per 1,000 acres.

The best position for a waste weir is at one of the extremities of the embankment or dam. It should be formed in solid ground, and quite distinct from any made earthwork. It may happen that from the configuration of the ground some low gap occurs in the line of hills surrounding the reservoir, which by a slight cutting may be made available for the weir. When such is the case it should always be taken advantage of, so as to carry the floods as far from the bank as possible. To secure the greatest length of weir, it is often found convenient to construct the latter in a curved form (see *Plate* XVIII.), yet it must be remembered that this will produce unequal concentration of the overflowing water at certain parts. Another method is to have the weir at right angles to the general line of the dam. The water then flows over the weir towards steep natural ground and thence round a curved basin to the bye wash. In any case. the weir should be constructed of heavy masonry set in cement, the sill being built of the largest procurable stones. The up-stream side should be protected against underscouring by a concrete apron. No temporary or moveable parts can be allowed, and materials and workmanship alike must be of the best.

The water after flowing over the weir has to find its way down to the natural watercourse below, and as the difference in level between the water in the reservoir and the bottom of the valley is considerable, it is evidently necessary to provide such a channel as will not only confine the flood water within due bounds, but will prevent its doing permanent damage to the masonry of the channel in its passage. It is, on the one hand, desirable to discharge the water as quickly and by as short a route as possible, but, on the other hand, not at such a velocity as shall be injurious to the stability of the work.

With inclines or ramps as in *Plate* XVII., or steps, the result is a high and continuously increasing velocity, which in many cases has led to the undermining of very massive masonry works. A certain uniform velocity can be obtained in one way only, viz., by having what are called "tumbling bays," *i.e.*, making the water fall over a series of weirs into a succession of pools (see *Plate* XIV. and *Plate* XVII., *Figs.* 5 and 6), and thus interposing between the falling water and the masonry below a water cushion. To prevent damage, the masonry is sometimes made arched in plan, the convex portion being up-stream (see *Fig.* 5, *Plate* XVII.), but this would probably be necessary only in exceptional circumstances.

In designing such a channel, the first thing to be determined is the depth of water that can safely be allowed to flow over each step, considered as an ordinary weir; the next is to regulate the height of the step and of the pool below. Formulæ for working out both these problems are given in *Molesworth's Pocket Book* (p. 298, Ed. 1893). The length of each pool should be at least ten times the height of the fall. All high falls should be avoided if possible. It may be necessary to provide *fish ladders.* A large pool at the bottom of the weir of sufficient length and depth to act as a settling pool for the falling water in flood will generally be provided ; fish can collect here and pass up the bye wash by the tumbling bays.

OUTLETS.

Of equal, if not greater, importance than the waste weir among the accessories of a reservoir is the *outlet.* It must be remembered that the embankment and the outlet are separate and distinct works, the one for the purpose of retaining water, the other for its escape under proper control. To attempt to blend the two into one work performing two separate and antagonistic functions has been the cause of many failures.

There are five principal ways whereby the outlet may be arranged :—

(1). Under the embankment, in a pipe with a valve at the downstream end (see *Plate* XVIII., *Fig.* 2, where the pipe is partly in a culvert).

(2). Under the embankment or dam with a valve in the middle, the pipe passing through a culvert (see *Plate* XXIII., *Fig.* 1).

(3). Under the embankment or dam in a culvert, with a valve at the up-stream end in a valve tower approached by a foot-bridge (see *Plate* XIX.).

(4). By a tunnel apart from the work altogether (see *Plate* XVIII., *Fig.* 1).

(5). By a syphon over the embankment.

In deciding which of these varions methods is best, it may be mentioned that a civil engineer of great experience has stated that he has as yet formed no definite opinion as to the best method of outlet. Circumstances may be so varied that a method which would be suitable in one place would be inapplicable elsewhere.

The first method, however, is universally condemned. At first it seems the simplest and cheapest, but it must be remembered that water under pressure is a very penetrating substance, and will certainly tend to leak along the surface of a pipe, or a stone or brick culvert laid through an embankment. Again, the embankment itself will certainly settle, and in so doing will probably fracture the pipe (see *Plate* XVIII., *Fig.* 2). Even under comparatively low embankments (in one case only 16 feet high), pipes have become fractured by unequal settlement, and in not a few cases disaster has occurred of a most serious description.

The evil is rendered more uncontrollable by the provision of the valves at the down-stream end only. This is obviously so foolish that few cases of such construction have occurred of late years, and the method is only mentioned here as a warning.

The plan of having a central valve and a culvert through the embankment and placing the pipes inside it, is more costly and difficult to construct than the method of having simple cast-iron pipes through the embankment. It is better, no doubt, than leaving the pipes in the embankment unprotected, but the culvert still is exposed, to a considerable extent, to unequal loading.

The central valve is worked from a valve well which is supported by masonry beneath. But the culvert on either side of the valve well is not supported except by the yielding puddle or other made ground, and is subject to the irregular weight of the mass above. To obviate this difficulty, that portion of the culvert immediately over the puddle trench has sometimes been built without any bond connecting it with the remainder of the work (see *Plate* XXIII., *Fig.* 1), so that a small subsidence may take place in the masonry without affecting the pipes. Practically, this does not work well, as settlement rarely takes place along a true vertical line, and friction is almost certain to cause damage.

Another evil of this system is that the up-stream or reservoir part of the culvert is inaccessible, and as the water in it will be under great pressure when the reservoir is full, it will be sure to find out any weak parts of the construction.

A still further evil of the valve well or shaft is that it is subject to unequal pressures on either side—on one side there is the weight of water as well as the earthwork, on the other side earthwork only. It runs the risk, therefore, of being pushed out of the perpendicular.

The two first cases, therefore, are not to be recommended.

The third case, where the outlet pipe or culvert is governed by a valve at the reservoir end, worked from a valve tower, is the best where culverts must necessarily be used. This plan does not do away with the disadvantages of unequal settlement in culverts, but it provides, at all events, for control over the water entering them.

The valve tower (see *Plates* XIX., XXI., and XXII.) is built near the toe of the inner slope, and has certain sluices worked from the tower above. Near the foot of the tower there should be a secure water-tight stopping or bulkhead, to prevent the egress of water in case of any failure.

The risk of settlement in the tower should be most carefully guarded against.

Inasmuch as the quality of the water will vary with the level at which it is drawn, there should be outlets or sluices at different levels in the valve tower (see *Plate* XXI.). Arrangements also should be made to permit of examination and repairs to the valves without stopping the flow of water.

It will be seen that to effect this it will not be sufficient to admit the water inside the tower at the same level as in the reservoir, as, in order to get at the valves, the supply must temporarily be stopped.

The most satisfactory arrangement is to have inside the valve tower a vertical stand-pipe with horizontal connections communicating with the reservoir. These horizontal connections are each governed by a valve *inside* the tower and a flap or door *outside* the tower in the water of the reservoir (see *Plate* XXI.). It is clear that each of these valves, except the lowest, can be repaired by shutting the outer flaps. The supply can still go on through the ones below.

Plate XXII. shows various forms of valve towers as manufactured by the Glenfield Co., taken from their catalogue.

Valve towers may be either built of ashlar or cast iron.

The fourth description of reservoir outlets, and that which of recent years has been considered by most authorities as the best, is by a *tunnel*. By this means the outlet is entirely distinct from the embankment. By a tunnel, of course, is meant a gallery mined through solid natural ground, not a masonry culvert first built in the open and then covered in with earth.

The flow of the water in this case would, as in the former, be governed by sluices from a valve tower, built in the reservoir as above described, or the sluices may be placed in a valve well situated about midway in the length of the tunnel, clear of the embankment.

In either case the pipes should immediately afterwards pass through a solid brick stopping, so that no water can penetrate into the tunnel beyond. The brick stopping may be arranged in the form of a horizontal arch abutting against the rock, and the bricks (which should be hard) may be keyed or bonded into cast-iron projections specially arranged on the pipes (*Plate* XXIII., *Fig.* 2).* The rock abutments should be cut back so as to prevent any possibility of water creeping round between the concrete of the tunnel and the natural strata. For construction of the tunnel, which properly comes under the heading of "Aqueducts," see next chapter. Sections are shown on *Plate* XX. and *Plate* XXIII.

SYPHONS.

In shallow reservoirs, where the depth of the water is not greater than about 28 feet, a syphon is a very good form of outlet. It is inadvisable to fix syphons to draw more than 25 feet.

The syphon may be carried over the embankment, but a better plan is to take it up the edge of the inner slope, where it joins the natural ground, and round the end of the dam.

Both inner and outer ends must be protected by valves. The inner end should be some feet higher than the outer end, and at the highest point there should be air valves (see *Chapter* IX.) and means of filling the whole. To cause the syphon to work, the inner and outer valves are closed, the whole is filled with water through the charging valve, after which the latter is closed and the other valves opened. The syphon ought then to work easily and freely.

Fig. 41 shows a syphon for drawing off water at different levels.†

In small reservoirs a valve tower may be dispensed with; the arrangement shown in *Fig.* 42 may be adopted.‡

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* This figure, taken from Mr. Binnie's lectures, does not show exactly what is here described, as the stopping piece is in the figure applied to a cast-iron tunnel lining, and not to actual pipes. The principle, however, is the same.

† From Glenfield Co.'s Catalogue.

‡ *Ibid.*

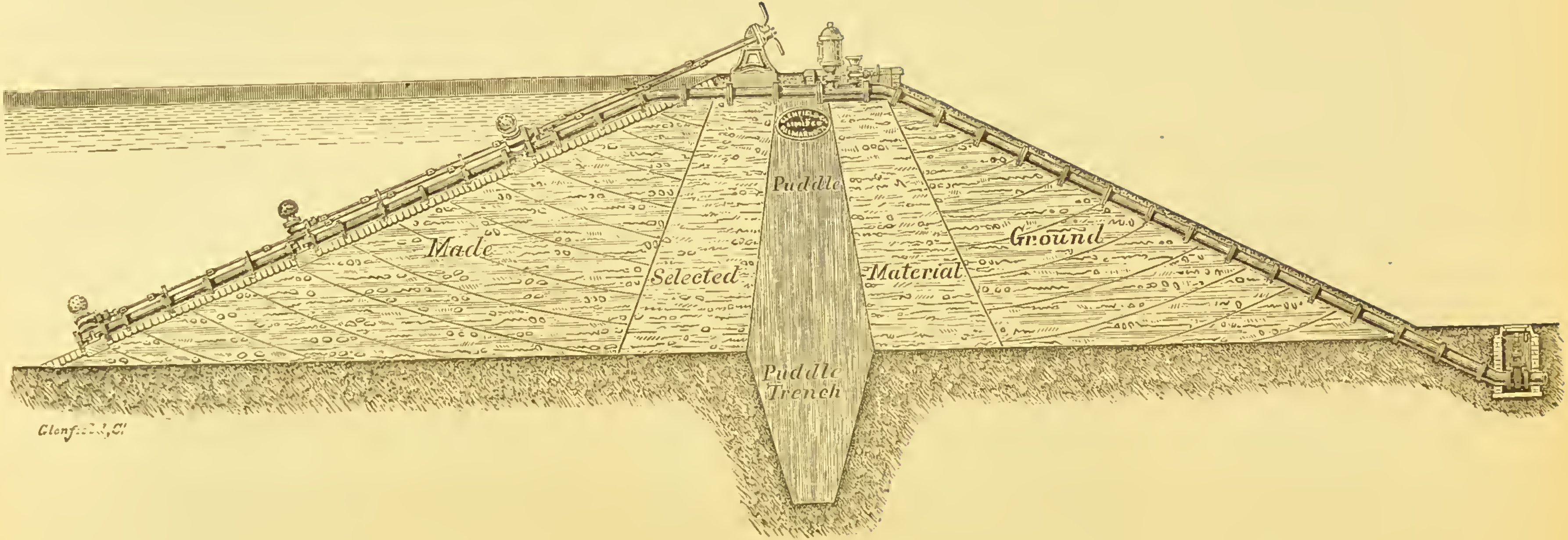
Puddle
Made
Selected
Material
Ground
Puddle Trench
Glenfield, C°

Fig. 41.

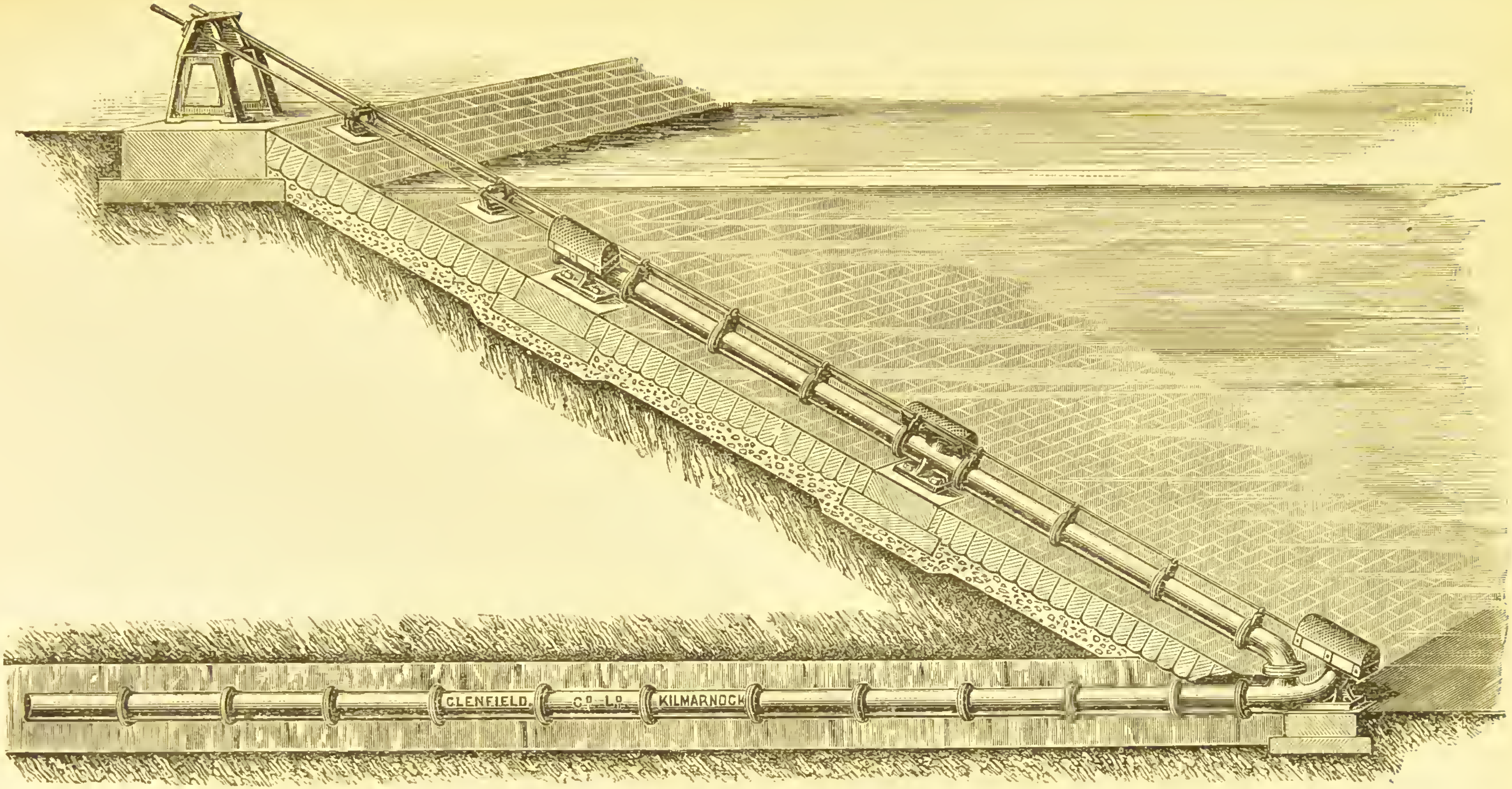

Fig. 42.

CHAPTER V.

AQUEDUCTS AND MAIN PIPES.

Aqueducts.—Tunnels.—Conduits.—Open Conduits.—Cut and Cover Work.—Monier System.—Asphalte.—Cast-Iron Pipes.—Joints.—Manufacture.—Testing.—Laying.—Wrought-Iron and Steel Pipes.

THE term "aqueduct" in a water-supply scheme means the whole course of structures for the passage of the water between the impounding reservoirs, and the supply or service reservoirs, whether such structures be tunnels, open channels, pipes, bridges, or any other form of duct. The same term in canal engineering is limited to a masonry bridge, in which the canal flows over a valley, in contradistinction to a "superpassage," where a river flows over the canal, or an "escape and regulator," where the canal and river cross the same level. It is important to bear these distinctions in mind in India, where irrigation canal works are common.

In canal engineering the water flows in an aqueduct open to the air, but in a water-supply work the bridge which carries the water will usually be so constructed that the flowing water will not be exposed to the air, both because of the evaporation which would follow, and because of the impurities which might be introduced into the water. Further, the bridge for taking the water supply of a community will also be almost invariably narrower than a canal aqueduct. Hence a water-supply bridge is not by any means the same as an aqueduct in a canal.

An example of a water-supply bridge is shown in *Plate* XXIV.

Water may be conveyed for distribution:—(1). By open conduits. (2). By covered conduits. (3). By pipes under pressure.

Sometimes it may be desirable, for motives of economy, to have *open channels* as conduits for the water, but the water which passes in such channels should invariably be filtered before being used. They are not desirable on the sides of steep hills, as they are liable to obstruction from the slope above, and they are also liable to intercept impure surface-water.

The theoretical considerations which govern the building of cross-sections and the slope of channels will be considered in a later chapter. Various cross-sections are shown on *Plates* XXV. and XXVI. It is here sufficient to say that the greater the velocity of flow, the smaller in cross-section, obviously, will be the channel, and, therefore, the cheaper its construction. But, on the other hand, there are limits to the velocity with which water should pass along any channel. A reasonable maximum limit in a masonry conduit is 5 feet per second. If a higher velocity than this is given, the chances are that the sides of the channel will be seriously worn away. If a velocity less than 2 feet a second is given there will be the chance of vegetable growth, especially if the channel is open to the air. The Army Sanitary Commissioners, 1882, suggest a fall not less than $\frac{1}{1000}$ or greater than $\frac{1}{300}$, unless pipes are used.

The best form of cross-section in an open channel is a semi-circle, but very frequently the sides of the channel are made sloping with a curve at the bottom (*Vide Plate* XXVI., which shows various sections recommended by the Royal Commission on Water Supply). Irrigation ducts are generally as in *Fig.* 43.

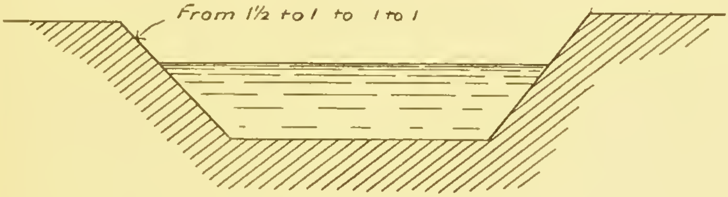

Fig. 43.

Where the aqueduct leaves the impounding reservoir, as we have formerly stated, the best form of exit is a tunnel through the original ground. The mouth of the tunnel will be, in the case of pipes, closed up, the stopping-piece of masonry being constructed in such a way that there is no possibility of leakage in the tunnel (see *Plate* XXIII., *Fig.* 2). Where pipes are not employed, and the tunnel itself is intended to be the conduit through which the water flows, it is still necessary to regulate the flow at the mouth of the tunnel by some form of sluice or stop-gate. And it is further necessary in every case that the water should pass through *strainers*, so as to prevent fish or floating matter from entering the aqueduct. These strainers are generally fitted with copper wire gauze of varying thickness, which are fixed in wooden frames, arranged to slide in vertical grooves, so that, if necessary, they can be raised up, removed and cleaned (see *Fig.* 44).

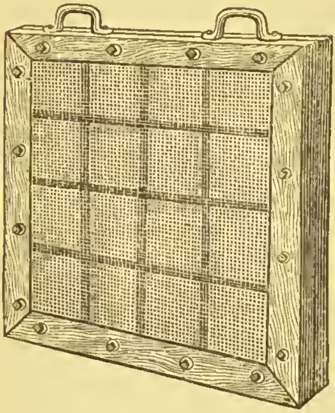

Fig. 44.

In the construction of the tunnel itself it is hardly necessary to say that the greatest possible care should be observed both with regard to alignment and levels. The alignment is of importance, because there should be no abrupt changes of direction, which would tend to alter the flow of water; and the levels are of importance, because on them depends, to a large extent, the quantity of water which will pass through.

Where pipes are laid inside the tunnels the interior section of the tunnel should be large enough to admit of perfect inspection of all parts of the pipes, and should, therefore, have sufficient headway to admit of the inspector passing without difficulty along the course.

It rarely happens that tunnels can be taken through rock without being lined. In some few rocks, such as granite, this is possible, but in the majority of cases lining is necessary, whether the tunnel be used as a conduit, or for pipes to be inserted inside it.

Portland cement concrete is, when obtainable, the best material for the lining of tunnels, but concrete of hydraulic lime is also very good. In the Glasgow waterworks the tunnels recently constructed were made of Portland cement concrete, 1 cement, 2 sand, and about 3 broken stone. The method of construction was somewhat as follows:—The concrete was laid at the sides of the tunnel, behind a framework carefully placed in position, the lagging-boards, holding the concrete in, being added as the sides rose higher and higher. At the roof of the tunnel, centerings for the arches were placed at about 6 feet intervals, and lagging-boards 12 feet in length were laid across to within a few feet of the crown of the arch. The concrete was placed in the direction of the arrows in *Fig.* 45 on either side, and rammed in as tight as possible between the lagging-boards and the roof of the tunnel. The centre portion, however, could not be constructed in this way, and for this purpose short lagging-boards, half as long as the others, were employed, and the concrete was put in at right angles, that is to say, longitudinally as regards the length of the tunnel, and thus each portion, 6 feet long, was completely filled up.

Sometimes it may be desirable to collect the pure water of the streams which are crossed on the line of a conduit, and at the same time to exclude all the turbid water which such streams may bring down with them in time of flood. In such a case the conduit is taken across the line of the stream in a leaping weir, plans and sections of which are shown on *Plate* XV. In this case, when the stream is running clear and not in flood, the water flows through the opening of the top of the conduit, but when it is flowing down in a heavy flood the velocity which it will then have acquired causes it to leap over the opening in question, and flow down the natural channel below.

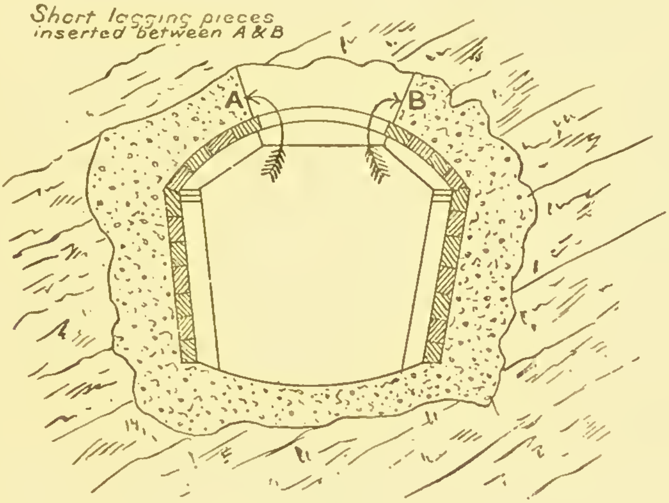

Fig. 45.

It must be remembered that where such water is allowed to enter a conduit, catch-pits or subsiding cisterns should be provided at frequent intervals, the floors being sunk some feet below the bottom of the conduit, so as to intercept any sand or solid matter which may be carried along.

If, through the nature of the country, the slope of the masonry conduit must necessarily be greater than that which would bring the velocity of the water within the limits above stated, it will be necessary to adopt a line of pipes (See *Plate* XXXVI., which shows a general typical section).

The advantages of iron or steel pipes are that they may be laid in a direct line following the natural undulations of the ground, as they are able to withstand a high internal pressure.

In this country water main pipes are generally made of cast iron. In America they are sometimes made of wooden staves bound with iron hoops or bands, but this is so seldom used in any work with which English engineers are connected that it is hardly necessary here to do more than simply refer to it.

Frequently a combination of masonry conduit and cast-iron pipe is adopted, the conduits being used on those parts of the ground where the water could easily flow within the limits of velocity by gravitation alone, and the pipes being used for the crossing of valleys. Valleys may be crossed either (*a*). By a masonry bridge. (*b*). A pipe bridge, *i.e.*, where the pipes rest on piers. (*c*). An inverted syphon. Where crossings of the last description are adopted, the lowest point being situated at a stream or river in the valley, the pipe should be carried across on a bridge, so as to be open for inspection, and should be provided with *scouring valves*, *reflux valves*, and in some cases self-acting *throttle valves.* These will be described in Chapter IX. The neglect of these precautions has often been the cause of much danger, expense and anxiety. It will be evident that at the lowest point the pipe is exposed to the greatest stress, fracture is there most likely to occur, and unless the pipe is easily accessible it may be extremely difficult to remedy any breakdown. Such an inverted syphon pipe passing across a valley should, at the points where it leaves the conduit and again joins it on the other side, be provided with *inlet and outlet* basins, the former being furnished with proper gratings to prevent any floating bodies entering the pipe. The outlet end of the syphon should be situated on a lower level than the inlet one, the difference in level depending upon the length of pipe, and being necessitated by the head required to overcome friction in the pipe.

The extent to which this plan of crossing valleys can be adopted will depend upon the strength of the pipes. *Plates* XXVII. and XXVIII. show the section of a portion of the aqueduct of the Murree water supply. It will be observed that in one case the head of water at the bottom of the syphon is nearly 1,350 feet, or 610lbs. per square inch. Mr. Binnie has given 600 feet as a safe limit, but that limit has been stated for large pipes, and it will be observed that the pipes on the Murree water supply are under 5 inches in diameter, and are of steel, whereas those on the Glasgow waterworks recently constructed are 48 inches in diameter and are cast iron.

If the pipes are likely to be exposed to vibration or to shocks the pressure will be largely increased, and before adopting a design involving the crossing of a very deep ravine every consideration should be given to the possibility of avoiding a breakdown by adopting a different method or route.

Where the quantity of water is not very large, and where it is not to be carried under great pressure, stoneware pipes may be substituted for masonry conduits; they are easily and cheaply constructed, and they may be made so as to be perfectly water-tight. The construction of such a conduit will, of course, be exactly similar to the construction of sewers, fully described in books on sanitary engineering. With stoneware pipes it is possible to have a pressure, according to Professor Burton, corresponding to a head of about 10 feet. Hence stoneware pipes may be laid down in part of the course up to a depth of 10 feet below the hydraulic gradient. With the improvements in the joints of sewer pipes, such as introduced by the Albion Clay Company (see *Figs.* 46, 46*a*, 46*b*), and other manufacturers recently, it is probable that this head may be considerably increased.

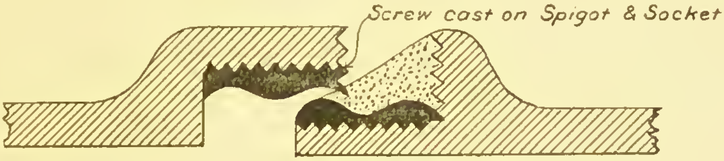

Fig. 46.

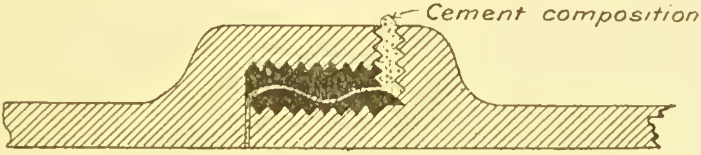

Fig. 46*a*.

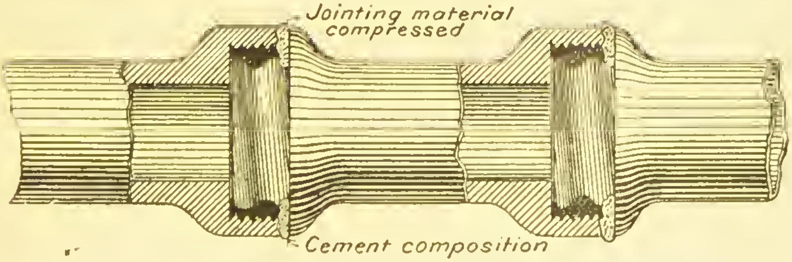

Fig. 46*b*.

Details of Masonry Conduits.

Although the advantages of cast-iron pipes are numerous, yet in countries where communications are bad, and the distances from a manufacturing depôt are great, it is probable that masonry conduits will be more economical. In many of our Indian stations this will be the case, and it is, therefore, worth our while to devote a little attention to the most satisfactory method of their construction.

It may be advisable in many cases to construct a dual system of conduits connected together at intervals. The advantages of this dual system are that any part of the system may be temporarily closed for examination and repairs, and if any breach should occur in one, the other will be available for supply. The connections between the sections of such a dual system will be made in what are called *stop-plank chambers,* or small connecting chambers with grooves, as shown in *Plate* XXXI., in which horizontal planks or baulks may be dropped, diverting the current in any required direction. That shown in *Plate* XXXI. is taken from the Glasgow aqueduct.

If the conduit is covered throughout its length, these stop-plank chambers will be found convenient places for admitting air into both systems.

The foundations of masonry conduits should be very carefully constructed, because any slight settlement which in any other structure might be of little consequence, in the case of a water conduit might lead to disastrous results. It should never be forgotten that water is a most penetrative element; a slight crack below the water line, due to unequal settlement of the masonry, will become enlarged by the action of the water, and serious leakage may take place. Hence it is absolutely necessary that the foundation must be rigid.

In India it is sometimes customary to line the whole of the brick or masonry channel with plaster made of the mortar of the country. This gives a very smooth surface for the passage of water, but it is not applicable where there is any chance of frost. Concrete is sometimes used in the construction of such conduits, but the case of Peshawar, where the conduit was constructed inexpensively of ordinary lime mortar concrete, and has since proved very troublesome, indicates that it is false economy to use any but the best material in the construction of the concrete. Where the conduit passes along an embankment, the masonry should be self-supporting, independently of any support that may be expected from the earth. This principle will be apparent when we remember that made earth is always liable to settle, and such settlements cannot be allowed to affect the masonry.

In cuttings, the conduits are sometimes constructed in what is called "cut and cover" work. In this case a trench is made, the bottom being excavated to the form of the lower half of the conduit, which is then covered over with an arch, and the trench filled in. This class of construction is simple and satisfactory, and should always be adopted where possible.

Conduits may sometimes be constructed to convey water under pressure. All precautions should be taken to make the masonry absolutely water-tight. Mr. Fanning, in his book on *Water Supply Engineering*, has described a special method designed by him for this purpose. He employs specially-moulded bricks, with mortices and tenons at the sides fitting into each other, and breaking joint in such a way as to utilize to the fullest extent the strength of the material. These bricks are laid with their greatest length round the circumference, and not longitudinally, as usually constructed. The conduit cannot be ruptured by the pressure of the water without shearing off numerous tenons in addition to overcoming the cohesive strength of the masonry. The brickwork is backed with rubble masonry or concrete.

Monier System applied to Conduits.

Of recent years a remarkable invention has been introduced admitting of many varied applications, namely, what is known as the *Monier system of concrete.* This system consists of a single or several layers of iron network, or iron rods crossed, but not interlaced, as in ordinary netting, embedded in cement mortar. The network is, as a rule, constructed or woven on the spot where the building operations are being carried out. The system is really the invention of a French gardener, who, in the course of constructing some flower pots, found that he effected considerable economy in weight by inserting a wire network in the cement. His next experiment was to construct a water tank, and the success with which this experiment was attended induced French engineers to apply the system in other matters. It was, however, a German engineer, Herr Wayss, of Frankfort, who perfected Monier's idea and adduced a formula according to which the system may be worked out. The iron network is embedded in the cement at that point where tension in the cross section of the concrete is at its greatest. Consequently advantage is taken of different qualities in the materials in such a manner as to utilize them in the best possible way.

This system has been very largely adopted abroad. In Berlin it is used for fire-proof flooring; in Austria it has largely come into use, so it is understood, for fortification, and in connection with the arches of railways. At Konigsberg, in Prussia, it has been applied to the construction of the conduits for water supply. *Figs.* 15 and 16, *Plate* XXV., give the section of such a conduit; it will be observed that the section is a parabolic arch, and that the thickness at the crown is very small.

The expansion of the cement has been proved by experiment to be equal to that of the iron. Hence the differences of temperature will affect any such structure as a whole but little. This system has now been under trial for 10 years in various European countries; it has been subjected to very thorough experiments. Objections which were raised, namely, that the embedded ironwork would rust, that the cement would not attach itself effectually, and that in process of time there would be disintegration, have proved to be groundless. The advantages of the system may, then, be summed up as follows :—

1. Great tensile resistance with minimum of weight of materials employed.
2. Practical indestructibility.
3. Great saving in space.
4. Great saving in foundations owing to the reduced weight of the superstructure.

English engineers have been slow to recognize the advantages of this system, but considerable public attention has now been directed to it. Whether the same satisfactory results would take place if hydraulic lime mortar were used instead of cement has not yet been proved by experiments. The mortar hitherto used has been usually in the proportion of 1 part Portland cement to 3 of sand.*

Asphalte may be very profitably used in the lining of masonry channels. The elasticity of this substance renders it very suitable for those situations where slight settlements of foundations may be feared, and the fact that it is quite water-proof is also a great point in its favour. A number of experiments have been made in various parts of America in the use of asphalte for reservoir linings. It has been found to be insoluble in water, and it imparts no taste or colour to the water coming in contact with it. It is very easily repaired, and new material can be made to unite perfectly with it. Possibly the cost of this substance in out-of-the-way parts of the country such as some of our Indian stations, would render its use prohibitive. On the other hand, it is well to note that where this substance is obtainable, as in the West Indies, it is most useful in reservoir and conduit construction.

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* See also *Engineering Record*, 12th May, 1894, p. 383.

Where the conduits are crossed by watercourses it is often desirable that the latter should be taken under them by inverted syphons formed of pipes, or of water-tight masonry. Where, on the other hand, conduits are taken across railways or roads, it will generally be necessary to adjust the levels in such a way that a crossing may be effected by means of a pipe-syphon. Where the necessities of the case do not demand the pipe being constructed in syphon form, *i.e.*, when the natural level of the channel will give sufficient headway to the road, it will frequently be found more easy to form a crossing in a pipe than in a masonry channel. In countries where frost may be expected it will be necessary to protect the pipe by a casing filled with some non-conducting material. An example of this is shown on *Fig.* 47.*

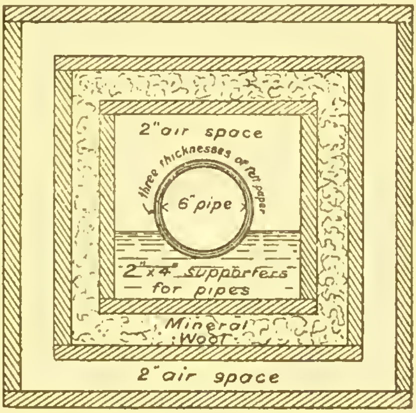

Fig. 47.

For the purpose of measuring the quantity of water passing through a conduit, *gauge-basins* are sometimes used. These gauge basins are simply subsidiary tanks built at the side of the line of the conduit, and connected with it by sluices. The capacity of the basin is known, and, therefore, the quantity of water which fills it in a given time will indicate the amount discharged.

Where the slope of the country is so steep that the conduit following the natural contour of the ground tends to become a torrent, and where it is considered undesirable to use pipes, a tank known as a *balancing reservoir* will be necessary. The object of this balancing reservoir is to check the flow of water, which has time to settle in the reservoir and flow out thence with diminished velocity.

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* From an example in *The Engineering Record*, also illustrated in *Plate* XXX.

The dimensions and style of construction of such tanks vary according to the magnitude of supply, but in most cases they may be just sufficiently large to enable the flow of water to be completely checked. The design will be generally the same as that of settling tanks (see Chapter VI.).

CAST-IRON PIPES.

The arrangement of the theoretical sizes of pipes in a given system will be dealt with in a subsequent chapter. It is perhaps sufficient to say at present that the *quality* of the water to be conveyed should be taken into account in estimating these diameters, because in the course of a few years there will be, with many qualities of water, a very considerable amount of incrustation, which will diminish largely the quantity supplied. Again, the probable future demand for water must receive careful attention in considering the question of size of pipes.

There are two forms, generally speaking, of connections in cast-iron pipes, the one form being the *flange joint* and the other the *spigot and 'socket joint.* The flange joint is made water-tight by covering the face of the flange with red lead putty, embedding a piece of string for two or three turns and screwing up (see *Fig.* 48). Another method is to insert a ring of some soft material, such as guttapercha or lead, between the flanges (see *Fig.* 48). The advantages of flange joints are that they can be taken apart and put together much more easily than the other sort, and they are also very useful for connecting pipes with meters, valves, and similar fittings. There are, however, certain objections to them; the flange is in itself a source of weakness, they do not pack so easily as the other kind, and they are, therefore, not so suitable for sending abroad; they do not admit of expansion and contraction to the same extent; and it is not possible to construct them, as a rule, so cheaply. The flanges may be secured by 4, 6, or 8 bolts. Four bolts are used for pipes up to 6½ inches diameter, 6 bolts up to 11 inches, and 8 for larger sizes.

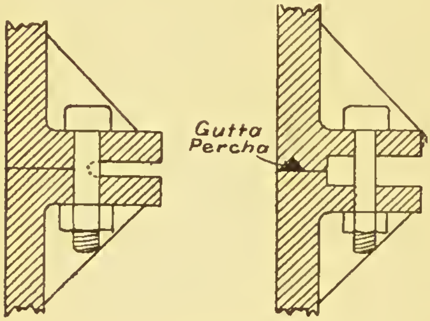

Fig. 48.

The spigot and socket joints are divided into two kinds, namely those with *turned and bored* joints and those with joints to be *run with lead.* In the former case the pipes are as shown in *Figs.* 49 and 50, the turned spigot fitting accurately into the bored socket. In the latter case the joint is as shown in *Figs.* 51 and 52. Where there are large quantities, the extra cost of turning and boring the pipes is not great, as machines can be arranged to turn out the work very quickly. There is a saving also in the construction. Hence it is cheaper to lay a pipe with turned and bored joints than with leaded joints.

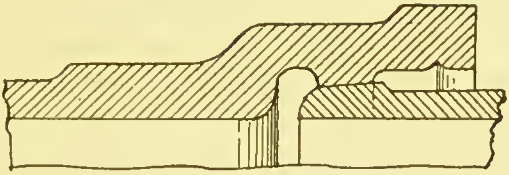
Fig. 49.

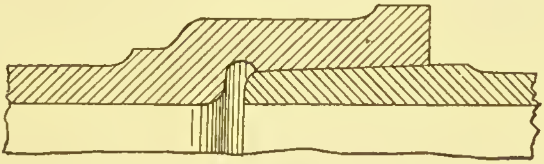
Fig. 50.

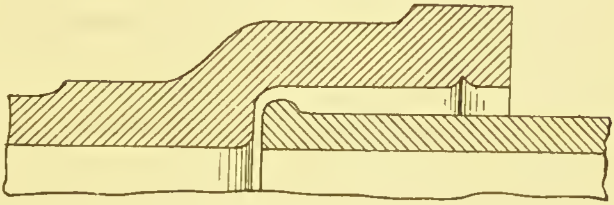
Fig. 51.

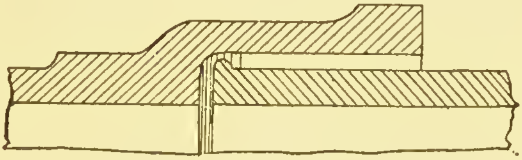
Fig. 52.

There are also other advantages with turned and bored joints. They can be much more rapidly laid than leaded pipes, and they allow a little play, in event of a slight settlement, without leakage. So also in taking the line round a wide curve to avoid an obstacle, it is possible to do so with turned and bored joints more effectually, in the opinion of many engineers, than with leaded pipes, because of the irregularity of the lead seal in the latter case.

The method of securing a turned and bored joint is as follows:—The turned and bored parts of the pipe are thoroughly cleaned, and are then smeared over with either a solution of salammoniac or a mixture of tallow and resin, or with thin red lead or liquid Portland cement. The spigot is then inserted in the socket and the pipe rammed home. This may be done by placing a block of wood at the end, and carefully tapping it with a maul. The object of the salammoniac is to rust the pipes together, practically making one continuous pipe. The great objection to turned and bored joints is that there is no allowance for expansion and contraction; so, if the pipes are laid in very cold weather, they tend to buckle with increase of temperature, or if the pipes have been laid in hot weather the joint will tend to draw asunder. It is sometimes customary to avoid the chance of leakage by having the turned and bored joints run in with molten lead, but if lead is to be used at all there is no reason why turned and bored joints should be used. Turned and bored joints are not suitable for heads over 300 feet, but for ordinary barrack services they are very well adapted.

Joints run with lead are suitable everywhere, except where the pipe may have to be broken for repair or for the insertion of a branch, valve, or other fitting. The following is the method of jointing such pipes:—The spigot is inserted in the socket, and is caulked with white or untarred yarn, rammed home with a caulking iron. The mould for the lead is formed by laying round the pipe at the socket a collar of rope, well greased with tallow or wet clay. A luting of clay is then put round the end of the socket, leaving the end of the rope collar free. This is then withdrawn, and the orifice enlarged and trimmed to receive the molten lead. Into the orifice the molten lead is run, the clay prevents the lead from spilling, and the metal presses on the top of the yarn, completing the joint. The ring of clay is then removed, and the lead is thoroughly caulked with a caulking iron. The end of the socket should be left clean and smooth.

The chief difficulty in the operation is to chip and caulk the joint *underneath*, where there is little room for the caulker to work: hence, in supervision, joints should be more carefully examined underneath than on the top.

Where leaded joints are employed they are troublesome to unseal and remove in case of fracture. Generally speaking, the fractured part can be cut round and replaced with a fresh piece and collar joints, as described later, without having to break away a whole length.

There have been a good many different forms of spigot and socket joints; the most usual are shown in the accompanying figures. *Figs.* 51 and 52 are the types used by the India Store Department. The depth of the lead depends upon the pressure to which the pipe will be subjected; it is generally about 2 to 2½ inches, or about half the total depth of the socket.

The importance of having pipes water-tight, under the great pressures to which they may be subjected, makes it most essential that the whole process of manufacture, testing, and laying, should receive special attention on the part of the engineers charged with the execution of the work. However carefully the sizes and weights of the pipes may be specified, it will be necessary for some trustworthy person to watch the manufacture throughout, in order that the chances of failure may be reduced to a minimum. A certain amount of consultation may be entered into with the manufacturers, because some are in the habit of using an iron of greater strength than others, and it may be desirable to allow a contractor to tender for a form of socket that he has been in the custom of making. The lengths of pipes are generally, in English practice (for 3 inches in diameter and upwards), 9 feet, exclusive of socket. The lengths of the sockets and their dimensions are given in the specification in Appendix II. There is some difference in practice, however, and here again it may be wise to modify the specification in order to suit the practice of a particular pipe founder. These matters will vary with local considerations, and the rules given in Appendix II. will, probably, be found to give a very fair average.

All pipes should be cast vertically, or, in the case of small pipes under 4 inches diameter, at an angle of 45°, from a good quality of pig iron remelted in a cupola; the socket end should be downwards, so that the ends which have to resist the blows of driving and caulking, gain additional strength by being cast under pressure, and there should be a head of 1 foot of metal, afterwards cut off in the lathe. The object of this head is to ensure compactness in the iron in the socket end. The moulds and cores must be scrupulously smooth and clean; lumps in the mould cause honeycombs in the iron, and moulds with straw bands may cause ribs in the pipe. The casting should be cooled slowly, so as to avoid all unequal contraction. The pipes should be free from all air-holes, cold shuts, cracks and all visible defects, and they should be smooth both internally and externally. Pipes with "scabs" (due to the sand breaking away from the moulds) even if cut off and filed smooth, should be rejected, as it is certain that the displaced sand is scattered throughout the metal, and is, therefore, a source of weakness. If, for any special reason, the pipes have to be unusually thick, extra care must be taken in the cooling of the castings, because a want of uniformity in such cases will make the castings weaker than those of ordinary thickness. Test bars, of the same iron as the pipes, should be tried for breaking weight. Bars 3½ feet by 2 inches by 1 inch are cast and laid flat on supports 3 feet apart. They are loaded gradually with 30 cwt. With this load a bar should have a deflection of not more than ·4 inches without showing any signs of breaking.

It is sometimes customary to specify that certain letters should be cast on the sockets of the pipes. The consecutive number, year, and the maker's name are sometimes cast on each pipe, the numbers of rejected pipes being disfigured by a chisel cut, and no number of a rejected pipe must be replaced.

As soon as the pipes are cool they should be tested with a 4-lb· hammer to discover any of the flaws above mentioned which may possibly be existing. If there are any bubbles or cracks, the sound of the iron when struck will be dull instead of ringing. They should then be treated with Dr. Angus Smith's protective process, but it is important that they be absolutely free from rust when so treated. If it is not possible that the dipping of the pipes in this protective bath be performed immediately after they leave the foundry, they should receive a coat of linseed oil to protect them until they are ready for the process, and no pipes should be dipped after rust has set in. They should be immersed in a bath of coal tar pitch prepared as follows :—The tar is to be boiled or distilled until the naphtha is removed and it attains about the consistency of wax, after which 5 or 6 per cent. of mineral oil is to be added. The composition is heated in a suitable vessel to a temperature of from 300 to 400° Fahrenheit, and so maintained during the whole of the process. When the process is complete the pipes are lifted out of the bath vertically, so that the surplus composition may flow off, leaving a thin uniform coating on all sides of the iron. No pipe should be dipped until the inspector has examined it as to cleaning and rust, and subjected it thoroughly to the hammer test. The inspector should also select certain pipes as samples, immerse them in clear water for at least 24 hours, and if the water is contaminated by the tar, it will be a proof that the process has not been thoroughly carried out.

The reason why it is important that the pipes should be coated thoroughly, and as soon as possible, is that on the efficiency of the coating depends not only the durability of the pipe, but the efficiency of its duty. It has been found by experiments that pipes which have not been subjected to this process become in the course of time so incrustated that they lose about ⅓ of their efficiency, or, in other words, the discharge of water is reduced between 30 and 40 per cent. With imperfect coating a pipe may be eaten up with acids underground, and cause a leakage difficult to detect and expensive to remedy. Pipes should also be tested for *straightness and uniform thickness* by a disc gauge on a long handle, the disc being equal in diameter to the calibre of the pipe, and both disc and handle rigid. For uniform thickness, calipers should be used. A deviation of $\frac{1}{8}$ inch is permissible. Pipes should also be *weighed*, and the weight compared with the standard. A deviation of 5 per cent. is allowable on the excess side, but if it is lighter than the standard, it should at once be rejected.

The next test is the hydrostatic test for strength. Some engineers are of opinion that this should be carried out before the pipe is subjected to the coating process. If there is any reason to suspect that the pipes are of an indifferent quality, perhaps this may be advisable, but if work has been fairly well done, and it is probable that few of the pipes will be rejected, it is more important that the pipes should be coated immediately after leaving the foundry than that they should be tested first and run the risk of being rusty before dipping. The hydrostatic test is a most important matter. The test should be at least double the head that would be in the pipes. In testing pipes, they are first filled with water, and it is important that they should be quite full, as if there should be any air in the pipes the latter may in bursting explode with violence and do damage to the bystanders. The apparatus in which the test is best carried on consists of two vertical shields (see *Plate* XXXIV.). In one of them there is an inlet for the water, furnished with a pressure gauge. The other shield is forced against the pipe by a screw at the other end. The pressure of the water is gained by a force pump, and is maintained for two or three minutes, during which time the inspector should strike the pipe in different places with a hammer. There should be no leakage nor oozing of the water through the metal. The machine shown on *Plate* XXXIV. is, of course, not absolutely necessary. It is quite possible to fill the pipe full of water, closing up the ends, and by pumping water into it with a pressure gauge (which should be tested before the operation commences), to ascertain the internal pressure. All pipes that are passed by the inspector should be painted at once with consecutive numbers, and those that are rejected should be broken. It is advisable, subsequently, to keep a record of what happens to each pipe, specifying it by its number, which should be quoted in invoices, etc. It is then possible to tell what happens to it, and if any mishap should occur, one can put the responsibility on the right person.

The next step is the conveyance of the pipes from the foundry to the work, and it will be observed that much care and supervision is necessary to avoid fracture in transit. Cast iron is well known to be a most brittle substance, and all precautions should be taken during transit to prevent sudden blows, especially at the spigots, sockets or flanges. Sometimes wrought-iron rings are shrunk on the spigots, and these have proved effective, especially in the cases of the carriage of pipes by sea, where, owing to the rolling of the vessel, they are exposed to risks of damage. When pipes are fractured at the ends they may sometimes be cut to shorter lengths and used for jointed pieces, or in going round curves. When pipes have to be conveyed across a rough country the difficulties of transit are often very great, and special arrangements will often have to be made to suit local circumstances. If the roads are smooth and level the pipes may be conveyed in timber carts, from the axles of which the pipes are slung in chains. For crossing soft ground the tires of the wheels may have to be made specially broad. It will frequently be cheaper to use wrought-iron or steel pipes in preference to cast iron, where the pipes have to be taken over a rough country.

The pipe trench is excavated with vertical sides to such a depth as will allow at least 3 feet of earth over the top of the main. The ground should be excavated on either side, so as to allow 6 or 9 inches between the pipes and the sides of the trench. For lead-jointed or flange pipes the trench should be enlarged, both in depth and in width, so as to facilitate the work of the jointers. Care must be taken to set out these enlargements from the actual net measurements of the pipes to be laid. Sometimes it is well to excavate the entire trench sufficiently wide to allow the jointers to work in it.

The bottom of the trench must be set out and carefully dressed with a proper slope and alignment, so that the pipes may rest upon the original ground at a required slope without any packing. In rocky ground a 6-inch bed of earth should be laid under the pipes, and in soft ground there must be artificial support. The pipes themselves are lowered into the trench either by a gyn or sheers. Sometimes two or three lengths can be laid together, the jointing being done above ground, but special care will have to be taken with the lowering of the lengths so jointed together. This method is *only applicable to small pipes*, and cannot be employed with those over 6 inches in diameter.

Where cast-iron pipes are unsupported, as, for instance, in the crossing of a stream, they may be trussed in the form shown on *Plate* XXX. Of course, if the crossing is a long one, it will be necessary to support the pipe at intervals on piers.

There are one or two other matters in connection with the construction of leaded joints which it is necessary to allude to here. In order to avoid the occurrence of air-holes and other flaws in the joints, both the spigot and socket must be perfectly dry and clean, and the pouring in of the lead should be completed at one operation without interruption. The pipes should be laid uphill from the scour-valves, sockets uppermost, so that the spigots will not tend to come out of the sockets by the action of gravity. The lead used must be pure (what is called soft blue pig lead), and its temperature requires attention; if too cold it may fail to run round the joint, and if too hot it is apt to set hard and become liable to fracture under the application of the caulking set or tool. With large pipes a jointing-ring is used instead of a clay-ring; this jointing-ring is made of iron or steel, hinged at the bottom, drawn together at the top, and formed so as to leave a triangular space all round its inner edge. Such a ring, however, would rarely be required in the construction of any waterworks for barracks or cantonment supply.

"Two methods of uniting adjacent lengths of main may be noticed*:—(1). By the insertion of one or two double spigot pipes, so that the spigots may be about six inches apart, with a collar joint. The collar or thimble, as it is sometimes called, is passed on to the first laid spigot, and is subsequently slid over the opening, when a lead joint is made at each end of it."

The method of collar joint shown in *Figs.* 53 and 54 is sometimes employed for the whole of the mains in preference to any other form of joint. It has been found by experience that with skilled workmen this form of joint gives simple and reliable results. Cracked pipes may in like manner be repaired. (2). "A method, that is applicable only to small pipes, is to cut the

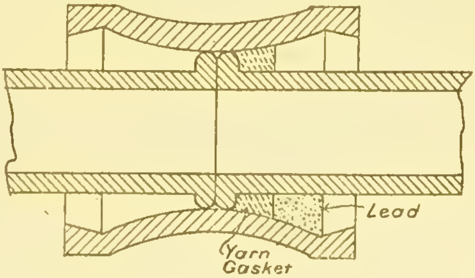

Fig. 53.

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* Turner & Brightmore, p. 356.

spigot end of the last pipe to be laid to such a length that it will just fit into its place, then to raise several pipes into an arch form so as to allow of the introduction of the metal spigot into its corresponding socket, after which the pipes are again lowered into the beds, and the union is completed by the jointers."

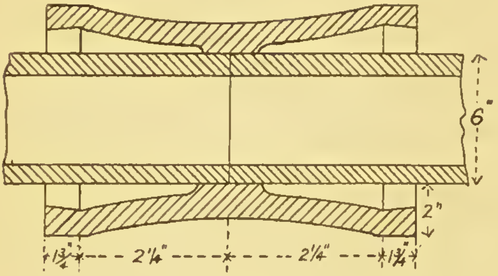

Fig. 54.

In going round curves lead-jointed pipes may be used, but turned and bored joints are not applicable. The permissible curvature in any case is limited to 480 feet radius, so that in situations where the curvature is considerable and irregular, special flexible joints are required. Such joints as that shown in *Fig.* 55 are chiefly used in taking mains over soft ground or on the bed of a river. *Fig.* 56 shows a form of flexible joint used in America, and described by Mr. Trautwine*.

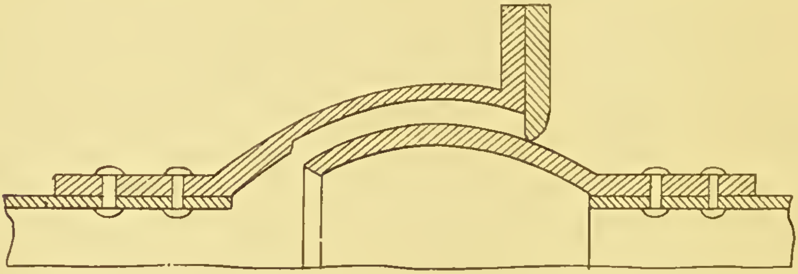

Fig. 55.

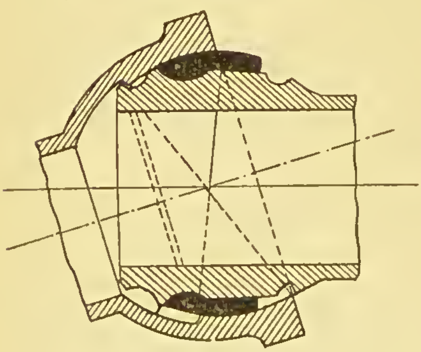

Fig. 56.

It is better, where changes of direction are necessary, to have pipes cast on a curve. Such pipes are kept in stock, of various curvatures and sizes, by most manufacturers (see *Plates* XXXII. and XXXIII.). Other special castings are, of course, more expensive than those which are kept in stock; it is desirable, therefore, in designing works, to arrange the pipes of such a description as may be readily obtained from manufacturer's stock. Bent pipes are specified, as a rule, of a certain radius and length, and it is desirable in laying such pipes to give them additional strength by backing or laying them in concrete, so as to counteract the pressure tending to force the joints at the bend.

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* *Pocket Book*. p. 296.

It is not necessary to have bends of larger bore than the rest of the pipes, in order to reduce the friction. Where a line is so short that the extra friction due to bends is appreciable to any extent, it is better to increase the diameter of the pipes throughout. The larger the radius of the bend, the less the friction.

In practice it is desirable to have the lengths of the bends equal, *i.e.*, the chords of the arcs being equal, and the radii of the curves varying. The usual lengths of chords are:—For 3-inch and 4-inch pipes, 1 foot $7\frac{7}{8}$ inches; for 5-inch and 6-inch pipes, 1 foot $10\frac{5}{8}$ inches; for 7-inch and 8-inch pipes, 2 feet $1\frac{1}{2}$ inches; for 9-inch and 10-inch pipes, 2 feet $4\frac{1}{4}$ inches. A straight piece is always given beyond the curved part for the spigot and socket, and the chord is measured from the centre of the pipe between the ends of the straights. The radius for a 90° bend is about $\frac{2}{3}$ chord, for a 45° bend twice that of a 90° bend, and so on.

If the ends of the pipes are covered with a collar joint, as in *Fig.* 53 or 54, under any circumstances, the length of the collar must be not less than twice the length of an ordinary socket. If a collar joint is used, as in *Fig.* 57, to fasten two socket ends which do not meet, the collar, which may be a cut piece of a pipe, should have a length beyond the ends equal to twice the diameter of the pipe.

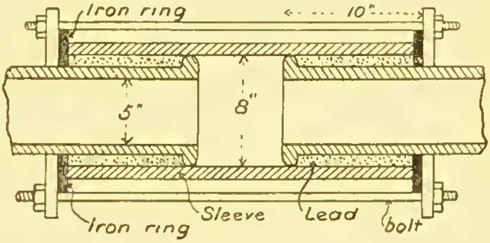

Fig. 57.

Before laying, each pipe should be tapped with a hammer to discover if any damage has occurred during carriage to site. The laying should be carried out, if possible, from the source or reservoir onwards. It is sometimes considered necessary (though in many cases it is not practicable) to test the pipes with the hydrostatic test after they have been brought to the site, or even after they have been finally fixed in their position. Where the pipes have travelled far (*e.g.*, from England to India), it is wise to repeat the hydrostatic test at the site of the works.

The final operation of filling in the pipe trench is important. The earth is carefully packed in thin layers under the pipe, so as to afford it a firm bearing. The upper part of the trench is then filled, and well trodden or rammed, the surface being restored as nearly as possible to the original condition.

When pipes are specified "to be delivered at site," it should be made clear that this means alongside the pipe line, according to the distribution plans, as it saves error and confusion, and a good deal of labour.

In specifying size of pipes, standard diameters, as shown in manufacturer's catalogues, should be adhered to. In the preparation of a project there is a temptation to reduce cost by "paring," *i.e.*, reducing thickness to a minimum. This is a great mistake, and often no economy, as a manufacturer will not depart from his standard dimensions without enhanced cost.

Thickness of Pipes.

We come now to consider the thickness of metal required in cast-iron pipes to give the necessary tensile strength under the various pressures to which they may be exposed. The following formulæ are given by eminent authorities* :—

If $T =$ thickness in inches of the cast iron.
$P =$ pressure in lbs. per square inch.
$p =$ safe tensile stress in lbs. per square inch.
$R =$ radius in inches $= \frac{1}{2}D$ the diameter.

Then

$$T = \frac{P}{p} R \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1).$$

Professor Reuleaux gives

$$T = \frac{P}{p}\left(1 + \frac{P}{2 \times p}\right) \times R \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2).$$

These do not apply to pipes under abnormal pressure, as in hydraulic machinery, which we need not here discuss.

Mr. Trautwine† also adds :—"Want of uniformity in the cooling of thick castings makes them proportionally weaker than thin ones, so that, in order to reduce thickness in important cases, we should use only the best iron re-melted three or four times, by which means an ultimate cohesion of about 30,000lbs. per square inch may be secured. Under a pressure of 8,000lbs. per square inch water will ooze through cast iron 8 or 10 inches thick, and under but 250lbs. per square inch through ·5 inch."

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* Trautwine and Turner & Brightmore.
† *Pocket-Book*, p. 233.

Mr. Fanning gives the following formula:—

$$T = \frac{P + 100 \times D}{\cdot 4 \times p \times f} + \cdot 333 \left(1 - \frac{D}{100}\right) \dots\dots\dots \dots \quad (3).$$

In this f is the factor of safety. The addition of 100 is to allow for ramming.

Taking the ultimate tensile strength of cast iron at 18,000lbs., and a factor of safety at 8, we get the following table*, in which is added $\frac{3}{10}$ inch to allow for rough handling, etc.

Column A is the thickness calculated by (1).
" B " " " " (2).

Head, in feet.	50		100		200		300		500		1,000	
Pressure, lbs. per sq. in.	21·7		43·4		86·8		130		217		434	
Diameter.	A	B	A	B	A	B	A	B	A	B	A	B
2 inches	·36	·31	·37	·32	·38	·34	·39	·36	·42	·40	·48	·51
3 "	·37	·31	·38	·33	·40	·35	·42	·40	·45	·45	·54	·60
4 "	·39	·32	·40	·34	·42	·38	·45	·42	·50	·50	·61	·72
6 "	·41	·33	·43	·36	·47	·42	·50	·48	·57	·60	·75	·94
8 "	·45	·34	·47	·38	·52	·47	·57	·55	·66	·70	·90	1·15
10 "	·47	·35	·50	·40	·56	·50	·62	·60	·74	·81	1·04	1·35
12 "	·49	·36	·53	·42	·60	·54	·67	·66	·82	·91	1·18	1·57

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* Trautwine, *Pocket Book*, p. 233.

Sir G. Molesworth gives the following formulæ (p. 311, Edition 1893):—

Let H = head of water in feet.
P = pressure in lbs. per square inch.
d = internal diameter of pipe in inches.
t = thickness of metal in inches.

$$P = 0{\cdot}433\,H \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (4).$$

$$t = {\cdot}000125\,Pd + {\cdot}15\sqrt{d} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (5).$$

As a good specimen of English practice we give the following table from the Glenfield Company's catalogue:—

SPIGOT AND SOCKET C.I. WATER PIPES.

3 *to* 14 *inches diameter, inclusive,* 9 *feet long plus the socket.*
15 *inches and up* ,, ,, 12 ,, ,, ,, ,, ,,

Internal Diameter.	Tested to a Water Pressure of—															
	400 Vertical Feet.				500 Vertical Feet.				600 Vertical Feet.				700 Vertical Feet.			
	Thickness.	Normal Weight of each Pipe.			Thickness.	Normal Weight of each Pipe.			Thickness.	Normal Weight of each Pipe.			Thickness.	Normal Weight of each Pipe.		
Inches.	Inches.	Ct.	qr.	lb.	Inches.	Ct.	qr.	lb.	Inches.	Ct.	qr.	lb.	Inches.	Ct.	qr.	b.
3	·368	1	0	10	·375	1	0	14	·400	1	0	23	·428	1	1	4
4	·375	1	1	24	·397	1	2	6	·420	1	2	16	·443	1	2	26
5	·405	1	3	22	·428	2	0	9	·451	2	0	22	·473	2	1	6
6	·437	2	2	0	·459	2	2	14	·481	2	3	0	·502	2	3	14
7	·450	3	0	0	·473	3	0	18	·496	3	1	8	·518	3	1	20
8	·460	3	2	0	·485	3	2	21	·510	3	3	14	·535	4	0	17
9	·480	4	0	7	·506	4	1	3	·532	4	2	0	·560	4	3	0
10	·500	4	2	7	·527	4	3	7	·555	5	0	7	·582	5	1	7
12	·560	6	1	0	·594	6	2	14	·627	7	0	0	·661	7	1	14

For further details see specification, Appendix II., paragraph 80.

The Glenfield Company give rather less thickness than American manufacturers. The following table shows the thicknesses as manufactured by Messrs. Cornell, Hiscox & Underhill, of New York. It is noteworthy that in America the pipes are cast in lengths of 12 feet 4 inches, including socket, or 440 lengths to the mile when laid:—

Size.	50′ Head or 22lb. Pressure.		100′ Head or 43lb. Pressure.		200′ Head or 86lb. Pressure.		250′ Head or 108lb. Pressure.		300′ Head or 130lb. Pressure.		400′ Head or 174lb. Pressure.		Contents for 1′ in length.	Weight of Lead per Joint, about.
	Thickness of Metal.	Weight per Length.	Thickness of Metal.	Weight per Length.	Thickness of Metal.	Weight per Length.	Thickness of Metal.	Weight per Length.	Thickness of Metal.	Weight per Length.	Thickness of Metal.	Weight per Length.		
	In.	Lbs.	In.	Lbs.	In.	Lbs.	In.	Lbs.	In.	Lbs.	In.	Lbs.	Gals.	Lbs.
2	·29	63	·31	67	·35	76	·37	81	·38	86	·40	91	·163	2¼
3	·32	139	·33	142	·34	148	·35	151	·36	156	·37	163	·367	3½
4	·36	198	·37	203	·38	213	·39	218	·40	226	·41	238	·652	4¼
6	·40	321	·42	342	·44	364	·45	375	·47	390	·49	411	1·469	6¼
8	·45	482	·46	500	·49	538	·51	555	·53	582	·56	620	2·611	8¼
10	·48	649	·50	676	·54	739	·56	760	·58	799	·62	856	4·081	10¼
12	·52	828	·54	869	·59	949	·61	1002	·64	1042	·69	1123	5·876	13

On *Plates* XXXII. and XXXIII.* are shown the special castings usually kept in stock by manufacturers, from whom details of the sizes should be obtained before preparing any project. The design should be arranged, as previously pointed out, to suit stock articles, as other special castings cost relatively more money.

Wrought-Iron and Steel Pipes.

The treacherous nature of cast iron, its want of ductility, and the difficulty of ensuring uniformity in the structure owing to unequal cooling, have caused attention to be paid of recent years to the use of wrought iron and steel in the construction of water pipes.

Wrought iron or mild steel has the following *advantages* in pipe construction:—(1). It is lighter (relatively to its strength), and, therefore, easier to handle. (2). It is tougher, and, therefore, may be thinner for a given pressure. Hence it is cheaper *per foot run* of pipe, although the cost *per ton* is greater. (3). It is more ductile, and it is, therefore, not liable to be broken in transit, and may be bent through an angle up to 25°. (4). Fewer joints are required. On the other hand, there is the disadvantage that it has greater liability to rust. This is such a formidable drawback that it has hitherto outweighed, in the opinion of many engineers, the great advantages. Wrought iron is more liable to rust than cast iron, and steel more than wrought iron, and as the metal for given strength in the case of wrought iron and steel will be much less than in cast iron, the action of rust will tend to leakage much more quickly in such a case. On this subject, however, manufacturers of steel pipes assert with confidence that they are able to protect their pipes from rust as efficiently, by coating the pipes with asphaltum, as cast iron is protected by Dr. Angus Smith's process.

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* Taken from the Glenfield Company's catalogue.

The 5-inch pipes for the Murree waterworks, above alluded to, under 1,350 feet head, were made of mild steel (Basic Bessemer) lap welded. The thickness was ·238 inch, whereas by formula (1) above quoted it would have been ·67 inch, which would give no allowance for ramming, etc. These tubes were tested to a pressure of 1,800lbs., the actual pressure being about 615. The 6-inch pipes for the Murree waterworks, with a working head of 650 feet, were ·203 inch thick, tested to 1,200lbs. pressure, the actual pressure being 140. The joints on these pipes were formed as follows:—The ends of the tubes were flanged, and these flanges fitted in the recesses of cast-iron collars or flanges, as shown in *Fig.* 58. The flanges were sent in halves to save freight.

According to Mr. Russell Duncan, of the Steel Pipe Company, Kirkcaldy, Fife, the best precaution against corrosion in steel pipes is to have them galvanized, then coated with natural asphaltum, or with a specially-prepared composition of pitch, tar, petroleum, linseed oil, and chalk. The composition is melted in a horizontal bath, heated to 250° F., and the pipes are immersed much in the same way as they are in the Angus Smith process. The surface thus produced is smooth, hard, and glassy. It is desirable to coat the pipes not only when they leave the manufacturer, but afterwards as they are being put into position, so that any surfaces which may have been damaged may be re-covered.

It is not sufficient merely to "galvanize" the pipes. Acids in the earth and the action of electrolysis in some cases tend to decompose the zinc coating, and corrosion thus sets in more rapidly than otherwise.

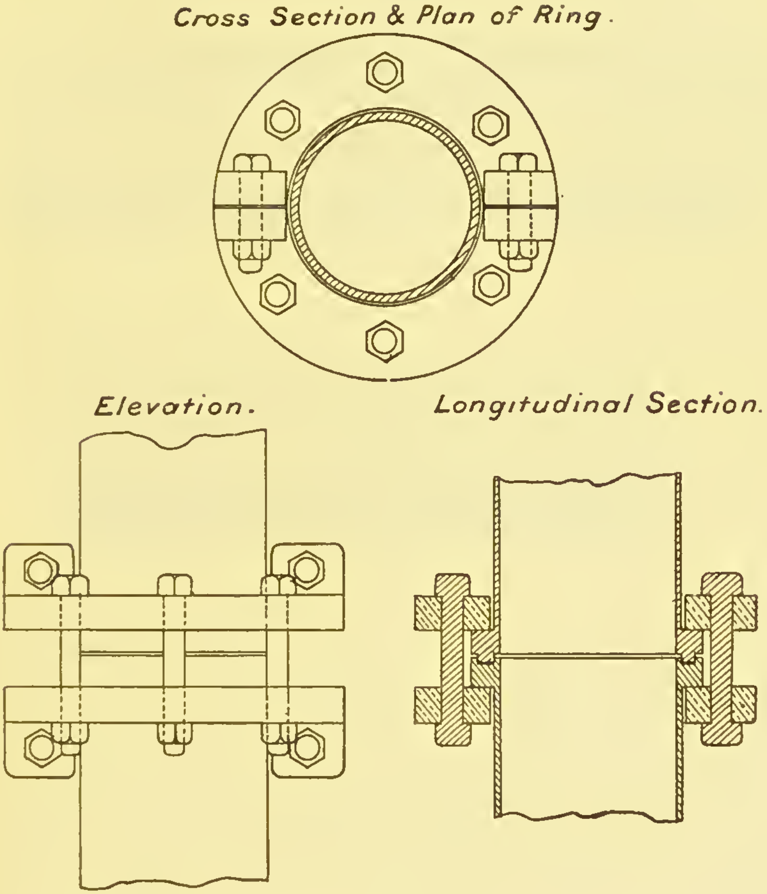

Fig. 58.

Steel pipes of small diameters, say up to 12 inches, are usually lap welded longitudinally. Above that they are rivetted, either spirally round the cylinder or in plates longitudinally and transversely (see *Fig.* 59). Those ordinarily required for barracks would be lap welded.

As regards the joints, it is clear that a screw joint will not be a strong one unless the part of the pipe in which the screw is cut is thickened or set up to receive the screw, as in *Plate* XXXV.

Other joints, all of which are good, are shown on *Plate* XXXV. The most of these admit of a considerable amount of play in the joint; they are simple, and can be made by men ordinarily accustomed to laying cast-iron pipes.

For pipes up to 6 inches diameter, Mr. Spencer (Globe Tube Works, Wednesbury) makes steel pipes with spigot and socket ends.

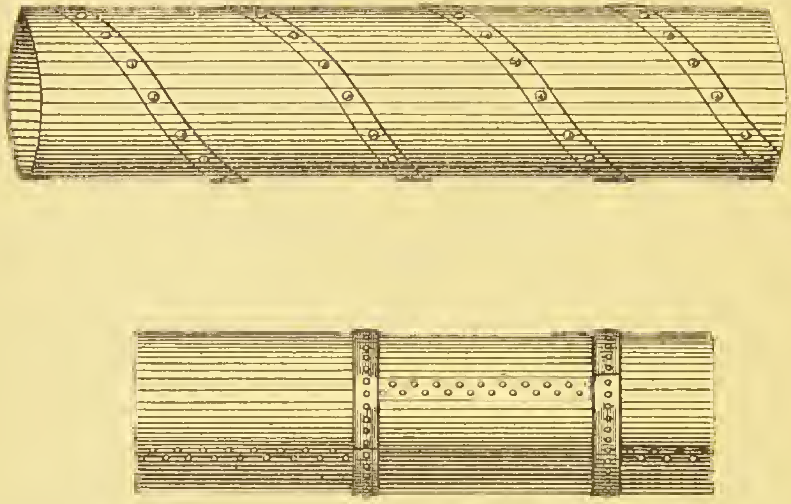

Fig. 59.

This joint can be fixed by the workmen accustomed to the ordinary cast-iron pipes with spigot and socket joints.

There is, therefore, less cost for freight (as the weight of steel pipes is much less than cast iron), and the loss by breakage is practically *nil* as compared with cast-iron pipes.

The steel pipes are usually made in lengths from 12 to 16 feet, so that fewer joints are required than in the ordinary cast iron in 9-foot lengths.

As regards the steel, the Steel Pipe Company at Kirkcaldy consider that the best results are obtainable from the Siemens-Martin process. Bessemer steel is used in other places, and probably, for small diameters, is quite sufficiently good.

ADDENDUM TO CHAPTER V.

The following information, kindly supplied by Major Courtney, R.E., of the India Store Department, is likely to be of use in connection with the subject of pipes for waterworks :—

WEIGHTS OF CAST-IRON PIPES.

The average weight of one cubic foot of cast iron is 448lbs., or 4cwt., hence the weight of a lineal foot of any uniform section is $\frac{4}{144}$ or $\frac{1}{36}$cwt. per square inch of sectional area.

Let d = bore, t = thickness of a pipe—both in inches.

A = area of a circle of diameter $d + 2t$.

a = ,, ,, ,, ,, d.

Then the sectional area of the pipe in square inches is

$$A - a \text{ or } \pi\,(d+t)\,t,$$

and the weight of a lineal foot in cwt. is

$$\frac{A-a}{36} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

or

$$\frac{\pi\,(d+t)\,t}{36} = \cdot 0873\,(d+t)\,t \quad \ldots\ldots\ldots\ldots \quad (2)$$

Formula (1) is the simpler if A and a can be found in a table of areas of circles.

The weights given in Table II. have been calculated as above; those given in Table I. are based on the details given in Tables II. and III.

The total weights inserted in indents should include the following additions to "book" or tabular weights :—

4 per cent. for pipes not exceeding 7 inches bore.
3 ,, ,, exceeding 7 and not exceeding 12 inches bore.
2½ ,, ,, ,, 12 ,, ,, 18 ,, ,,
2 ,, ,, ,, 18 inches bore.

The following formula is sufficiently accurate for approximate estimates of total weight of pipes in 9-foot lengths :—

Total weight of L feet in tons = $\cdot 005 \times L\,(d+t)\,t$; this includes an allowance of about 3 per cent. above "book" weights, and assumes that the weight of a socket is equal to that of 1 foot lineal of pipe.

TABLE I.

"Book" weights of Cast-Iron Pipes.

Bore.	Thickness.	Length.	Weight per Length.											
			Plain Spigots and Sockets.				Turned and Bored Spigots and Sockets.				Flanged Pipes.			
Ins.	In.	Ft.	Cwt.	Cwt.	qr.	lb.	Cwt.	Cwt.	qr.	lb.	Cwt.	Cwt.	qr.	lb.
2	$\frac{3}{8}$	6	0·547	0	2	5	0·554	0	2	6	0·537	0	2	4
$2\frac{1}{2}$	$\frac{3}{8}$	6	0·656	0	2	18	0·664	0	2	19	0·652	0	2	17
3	$\frac{3}{8}$	9	1·096	1	0	11	1·105	1	0	12	1·090	1	0	10
4	$\frac{3}{8}$	9	1·413	1	1	18	1·423	1	1	20	1·473	1	1	25
5	$\frac{13}{32}$	9	1·885	1	3	15	1·902	1	3	17	1·969	1	3	25
5	$\frac{7}{16}$	9	2·080	2	0	9	2·097	2	0	11	2·112	2	0	13
6	$\frac{7}{16}$	9	2·453	2	1	23	2·474	2	1	25	2·520	2	2	2
7	$\frac{1}{2}$	9	3·220	3	0	25	3·243	3	0	27	3·426	3	1	20
8	$\frac{1}{2}$	9	3·710	3	2	24	3·745	3	2	27	3·862	3	3	13
9	$\frac{9}{16}$	9	4·637	4	2	15	4·676	4	2	20	4·880	4	3	15
10	$\frac{9}{16}$	9	5·115	5	0	13	5·160	5	0	18	5·413	5	1	18
10	$\frac{5}{8}$	9	5·668	5	2	19	5·711	5	2	24	5·962	5	3	24
11	$\frac{5}{8}$	9	6·243	6	0	27	6·284	6	1	4	6·617	6	2	13
12	$\frac{5}{8}$	9	6·774	6	3	3	6.824	6	3	8	7·217	7	0	24
13	$\frac{11}{16}$	9	8·011	8	0	2	8·065	8	0	7	8·456	8	1	23
14	$\frac{11}{16}$	9	8·755	8	3	1	8·824	8	3	8	9·056	9	0	6
15	$\frac{11}{16}$	9	9·344	9	1	11	9·417	9	1	19	9·657	9	2	17
16	$\frac{3}{4}$	9	10·794	10	3	5	10·872	10	3	14	11·270	11	1	2
18	$\frac{3}{4}$	9	12·156	12	0	17	12·239	12	0	27	12·582	12	2	9
20	$\frac{7}{8}$	9	15·717	15	2	24	15·813	15	3	7	16·186	16	0	21

Lengths are exclusive of sockets, but inclusive of flanges.
Weights are inclusive of sockets or flanges.
The dimensions of the flanges are given in the table of flanges.
The weights of pipes differing from the above in thickness or other particulars can be obtained from the details given in Tables II. and III.

TABLE II.

"Book" weights of Cast-Iron Pipes, exclusive of Sockets or Flanges, in cwt. per lineal foot.

Bore of Pipe in inches.	Thickness of Pipe in Inches.									
	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{5}{8}$	$\frac{11}{16}$	$\frac{3}{4}$	$\frac{13}{16}$	$\frac{7}{8}$	$\frac{15}{16}$
2	·0777									
2½	·0941									
3	·1104	·1312								
3½	·1268	·1503								
4	·1432	·1694								
4½	·1595	·1885	·2182							
5		·2076	·2400							
5½		·2266	·2618							
6		·2458	·2836							
6½		·2649	·3054	·3467						
7		·2839	·3273	·3712						
7½		·3031	·3491	·3958						
8		·3221	·3709	·4203						
8½			·3927	·4449	·4977					
9			·4145	·4694	·5250	·5812				
9½				·4939	·5522	·6112				
10				·5185	·5795	·6412				
10½				·5430	·6068	·6712				
11				·5676	·6340	·7012				
12				·6167	·6886	·7612				
13				·6658	·7431	·8212	·8999			
14				·7148	·7810	·8812	·9654			
15				·7639	·8522	·9412	1·0308			
16					·9068	1·0012	1·0963			
17					·9613	1·0612	1·1617			
18						1·1212	1·2272	1·3339	1·4413	
19							1·2926	1·4048	1·5176	
20								1·4757	1·594	1·7130

TABLE III.

"Book" weights of Sockets and Flanges of Cast-Iron Pipes, in cwt.

Bore of Pipe.	Thickness of Pipe.	Plain Spigots and sockets. Drawing 2781.					Turned and Bored Spigots and Sockets. Drawing 2782.			Weight of Flanges per pair.
				Lead Joint.		Spun Yarn.			Lead Joint	
		Weight per Joint.	*Difference in weight for each difference of $\frac{1}{16}$-inch in thickness of Pipe.	Depth.	Weight.	Weight.	Weight per Joint.	*Difference in weight for each difference of $\frac{1}{16}$-inch in thickness of Pipe.	Weight.	
Ins.	In.	Cwt.	Cwt	Ins.	lbs	lbs.	Cwt.	Cwt.	lbs.	Cwt.
2	$\frac{3}{8}$	·0811	·0027	$1\frac{1}{2}$	1·67	0·18	·0874	·0029	1·41	·0709
$2\frac{1}{2}$	$\frac{3}{8}$	·0918			1·85	0·21	·0992		1·64	·0874
3	$\frac{3}{8}$	·1025			2·22	0·24	·1109		1·87	·0959
$3\frac{1}{2}$	$\frac{3}{8}$	·1132			2·40	0·27	·1226		2·10	·1044
4	$\frac{3}{8}$	·1239			2·77	0·30	·1344		2·33	·1845
$4\frac{1}{2}$	$\frac{3}{8}$	·1346			2·95	0·33	·1461		2·56	·1957
5	$\frac{7}{16}$	·2118	·0037	$1\frac{3}{4}$	5·73	0·64	·2290	·0041	4·48	·2432
$5\frac{1}{2}$	$\frac{7}{16}$	·2265			6·18	0·69	·2452		4·83	·2557
6	$\frac{7}{16}$	·2412			6·64	0·75	·2613		5·19	·3074
$6\frac{1}{2}$	$\frac{7}{16}$	·2560			7·09	0·80	·2775		5·54	·3646
7	$\frac{1}{2}$	·2739			7·66	0·86	·2977		5·99	·4799
$7\frac{1}{2}$	$\frac{1}{2}$	·2886			8·12	0·92	·3138		6·34	·5018
8	$\frac{1}{2}$	·3723	·0045	2	9·71	1·10	·4067	·0049	7·83	·5236
$8\frac{1}{2}$	$\frac{1}{2}$	·3902			10·23	1·16	·4264		8·24	·5454
9	$\frac{9}{16}$	·4126			10·87	1·24	·4511		8·76	·6557
$9\frac{1}{2}$	$\frac{9}{16}$	·4244			11·39	1·30	·4708		9·18	·6804
10	$\frac{5}{8}$	·4529			12·03	1·37	·4955		9·62	·7464
$10\frac{1}{2}$	$\frac{5}{8}$	·4647			12·55	1·43	·5152		10·03	·7606
11	$\frac{5}{8}$	·5373	·0049		13·07	1·49	·5835	·0054	10·45	·9108
12	$\frac{5}{8}$	·5764			14·10	1·61	·6262		11·28	1·020
13	$\frac{11}{16}$	·6204			15·22	1·74	·6744		12·30	1·065
14	$\frac{11}{16}$	·8244	·0061		19·54	2·09	·8928	·0066	16·38	1·125
15	$\frac{11}{16}$	·8729			20·77	2·22	·9457		17·41	1·186
16	$\frac{3}{4}$	·9276			22·16	2·37	1·0052		18·58	1·403
17	$\frac{3}{4}$	1·0555	·0066		23·40	2·50	1·1347	·0071	19·61	1·470
18	$\frac{3}{4}$	1·1079			24·63	2·63	1·1914		20·65	1·537
19	$\frac{3}{4}$	1·2959	·0073		25·87	2·77	1·3863	·0078	21·68	1·819
20	$\frac{7}{8}$	1·3682			27·42	2·93	1·4641		22 98	1·840

* Example—Weight of Plain Socket, etc., of 5″ pipe $\frac{13}{32}$″ thick $= 2118 - \frac{1}{2} \times ·0037 = ·2100$.
Weight of Plain Socket, etc., of 19″ pipe $\frac{9}{16}$″ thick $= 4529 - 0045 = 4484$.

CHAPTER VI.

PURITY OF WATER.

Relative Duties of Medical and Engineer Officers.—Amount of Solid Matter in Various Waters.—Organic Impurities.—Typhoid Fever and Drinking Water.—Examination of Water.—Collecting Samples.—Interpretation of Water Analysis.—Biological Examination.—Hardness.—Metallic Pollution.—Summary of Conditions of Purity.—Purification by Subsidence.—Arrangements of Settling Tanks.—Filtration by Sand.—Speed of Filtration.—Sizes of Sand Grains.—Details of Filter Beds.—Regulation of Flow.—Filtering with Substances other than Sand, Charcoal, Porous Stone, Polarite.—Cleaning Filter Beds.—Apparatus for Removing Hardness.—Miscellaneous Methods of Purification.

ALTHOUGH the quality of water is of primary importance, its consideration has been deferred until we are in a position to treat of filtration, a subject closely connected with quality.

The fact that the purity and abundance of water supply is of the first sanitary importance is fully recognized in the Regulations for the Medical Department of Her Majesty's army. The Principal Medical Officers are charged with the duty of ascertaining that the "supply is good and abundant, and perfectly protected from pollution."* In the field, they are charged with the duty of examining and reporting on the amount and quality of the water supply, etc. (Sec. I., Para. 120). In their reports, both annual and quarterly, the sources, quality and quantity of the water supply have to be considered; also whether it is wholesome, and what means of purification are in use, if such be necessary (Appendix IV.). Report has also to be made on "bad water, especially if any organic impurity exists."

From these regulations it is clearly recognized that the duty of ascertaining the quality of water, and watching over its purity during the time it is under storage, is primarily the duty of the Medical Department.

But inasmuch as the Royal Engineers are responsible for all the works connected therewith, it is quite clear that an appreciation of the principles on which such works should be designed is of the utmost importance to the designer. It is necessary, therefore, to trace the principles which underlie the choice of a good water, of proper means of purifying it, or of rendering it sufficiently useful in other respects for the use of the troops or other community to be supplied. Mutual co-operation between the medical and engineer branches will in all cases be most advantageous, the one giving opinion as to the quality, and the other as to means of supply.

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* *Regulations for Army Medical Services*, 1894, Sec. I., Para. 35.

Water is not found naturally in a state of chemical purity, *i.e.*, composed of one part of oxygen to two parts of hydrogen. Water may be obtained in this state by very slow distillation, and rain water, being distilled vapour subsequently condensed, is next in purity to that distilled in a laboratory, having from 1 grain to 3 grains of solid matter per gallon, or (expressing the same proportion in another manner) from 3 to 10lbs. of solid matter in the rain falling on one acre when the rain gauge registers 1 inch.

Such purity is, of course, unknown in water from springs, rivers, etc. In these there are always certain impurities, both gaseous and solid. As regards the former, the most common are carbonic acid—giving briskness of flavour—ammonia, sometimes sulphurous acid, and poisonous gases arising from decomposition.

The solid matter in water varies very considerably from the 1 grain per gallon above mentioned in rain water up to 14,488 grains in the Dead Sea. In Loch Katrine the amount is 2·3; in Windermere it is 5·78; in the Rhine at Basel it is 11·86; in the Thames, 20·17; in wells in chalk, 22·0 to 68; in the Atlantic Ocean, 2688·0.

The foreign substances thus present are, in the case of wells, rivers, lakes, much affected by the geological nature of the country whence they are derived, as pointed out in Chapter I.* The following table of various sources of supply is given by the Rivers Pollution Commissioners:—

Wholesome …	1. Spring water. 2. Deep well water.	Very palatable.
	3. Upland surface water.	Moderately palatable.
Suspicious …	4. Stored rain water. 5. Surface water from cultivated land.	
Dangerous …	6. River water to which sewage gains access. 7. Shallow well water.	Palatable.

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* See also Dr. Louis C. Parkes' *Hygiene and Public Health*, pp. 23—25.

The purest water is that obtained from rain flowing off a surface of primitive rocks. The most impure is probably tank water, and water from surface wells, in a populous and badly drained country.

It will be observed that some of the waters which are characterized as both wholesome and very palatable, *e.g.*, deep well water, are those which contain a considerable amount of solid impurities. It is, indeed, generally considered that water may contain solid matter up to 50 grains per gallon without being unfit for drinking, provided it also contains at least 3 per cent. of air and carbonic acid, and not more than ·5 grains organic matter per gallon.*

Inorganic substances, either in solution or suspension, are not, as a rule, injurious to health, though they may cause the water to be unpalatable. The filtration of water largely impregnated with iron will be subsequently described. As a rule, such waters are of use medicinally, though not of much practical value generally, when the salts in solution are over ·001 per cent.

Generally, one may say that the chief cause of danger in water is decaying or decomposing animal or vegetable substances.

One of the most notable warnings of modern times with regard to the connection between disease and water supply is furnished by the case of Hamburg in 1892. The water supply there was derived from the Elbe, and the works consisted of a pumping station and four settling tanks. There was no filtration, no cleansing of the tanks, the cisterns for house supply were choked with solid matter, and, finally, although the sewage outfalls discharged into the river below the town, the water was carried by the flood tide above the intake of the waterworks. The result was the loss of 8,000 lives by cholera. Altona, which also took its water supply from the Elbe, but had it filtered, enjoyed practical immunity from cholera at the same time that the pestilence was raging at Hamburg.

The case of Rawal Pindi has already been alluded to (see p. 30) as an instance where cholera was practically checked by the introduction of a good water supply. Another notable case is Quetta. In 1891 a pure water supply was obtained from a stream in Hanna Pass. The result was that in a cholera attack in July, 1891, out of a population of 9,346 there were only 26 cases, and it was found on enquiry that all the victims had used other water than that thus provided.*

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* Ansted. *Water and Water Supply.*

ORGANIC IMPURITIES.

The *quantity* of organic matter in a water which will render it impure and injurious to health is not so important as the *nature* of that matter, a question which more intimately concerns the medical officer than the engineer. There are, however, certain main principles which concern the latter.

The whole of this class of impurities may be classified as follows:—

(*a*). Dissolved organic matter.
(*b*). Suspended ,, ,,
(*c*). Bacteria.

Of these it will be seen that (*b*) and (*c*) can to a great extent be removed by settlement and filtration.

Class (*a*), however, is not so easily removed, and is by far the most dangerous form of contamination.

In the case of streams, Nature provides one method of purifying water charged with dissolved organic matter by oxidation† under the action of light and air. The extent to which this takes place must necessarily depend on a variety of circumstances, such as the depth and velocity of the current and the temperature. Professor Burton quotes the case of the Isar "rolling rapidly" below Munich, which has been the subject of experiment, and which is found to purify itself in about 10 miles. It has been established beyond a doubt that in any case a stream is rendered much less foul by flowing a few miles through an open country, though the extent of purification will vary with circumstances.

Professor Frankland has stated, in his report on the London water supply for 1894, that "various contributions of organic matter of animal origin enter into the water both of the Thames and the Lea above the intakes." "But," he further states, "it is gratifying to find, as the result of recent researches, that the zymotic matters of a pathogenic kind are rapidly destroyed in running water." Further, he assures us that it is now an established fact that efficient sand filtration would prevent the passage of pathogenic germs, did such exist, into the filtered water, even should they arrive in a living condition at the point where the water is abstracted for the purpose of the supply. Thus the hygienic objection to the use of filtered water taken from the Thames and the Lea is removed. This conclusion is supported by observations made in England, Germany, and America. "Efficient" filtration is the point insisted on. At the British Association Meeting, 1895, Dr. Frankland pointed out that bacteria are much more numerous in winter than in summer, and he showed that this was due to three conditions, viz., temperature, sunshine and volume of water. Sunlight is a very powerful germicide. A very powerful agent for reduction of numbers of microbes in river water is storage in a reservoir for even a short time (see also a paper read by the same authority on the 2nd August, 1895, published in the *Journal of the Sanitary Institute*).

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* However important a pure supply may be in other places, it is doubly so in the case of such positions of strategic importance as Rawal Pindi and Quetta, where, in event of war with Afghanistan or Russia, the ordinary garrisons would be largely augmented. An outbreak of cholera, such as that which occurred at Quetta in 1885, when war with Russia appeared inevitable, might result in the gravest national peril.

† This is not, strictly speaking, correct. The oxygen is merely the passive agent used by bacteria.

In deciding on which source of supply should be adopted out of several alternative schemes, an engineer would naturally, other things being equal, adopt that source which was uncontaminated with sewage or organic matter of any kind. But if no such desirable source were available, it does not follow that others less favourably endowed should be entirely rejected. Efficient filtration may accomplish in many cases the necessary purification, and the causes of contamination may also be reduced to a minimum. *Le mieux est l'ennemi du bien* is a useful precept to remember.

An example of what may be done with an unfavourable source of supply is afforded by the case of Shanghai, where the water is obtained from a tidal river, and yet, by careful arrangement of settling tanks and filter beds, is made quite wholesome (see *Plate* XXIX.),

TYPHOID FEVER AND DRINKING WATER.

A distinguished statesman* has recently, on a public occasion, alluded to the "reproach of typhoid fever" in English barracks as a military engineering question. It seems, therefore, fitting to introduce a few words on this subject from an engineering point of view.

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* The Marquis of Salisbury, at the annual dinner of the Institution of Civil Engineers, 1895.

The subject is, of course, surrounded with many uncertainties, but some facts may be taken as proved:—(1). That the disease is due to preventible causes. (2). That it is usually associated with the presence of a certain bacillus. (3). That this bacillus may be present in a drinking water, and although it may be present in other substances, yet its presence in water is probably the most common cause of the spread of the disease. (4). That long droughts tend to increase the danger of the contamination. (5). That the bacillus is frequently found in the sewage passing from persons or communities affected with the disease.

From the above facts we conclude that a thorough system of sewage disposal, entirely disconnected with drinking-water supplies, is one step towards the prevention of the spread of the disease.* Another most important step is the *purification of the drinking water*. This purification can be most readily and efficiently carried out by filtration, although some experts suggest, in addition, *sterilization* or boiling. The latter process would doubtless make the water absolutely safe, but it would involve, if carried out on a large scale, the establishment of special plant, and would add materially to the cost per unit in any water supplied to a community. We, therefore, turn our attention to *filtration*, and naturally our first enquiry will be whether experiment has proved that any known system of filtration has succeeded in getting rid of the bacilli above mentioned. Fortunately, we are in no doubt on this point.

Ever since 1887 the Massachusetts State Board of Health has been studying the laws of filtration at the Lawrence Experimental Station.† The details of their experiments will be alluded to again; it is perhaps sufficient here to point out the results as affecting typhoid bacilli. Billions of these bacteria were cultivated, and the water thus full of them passed through the filters. The experimental conditions corresponded to the state of affairs which would take place if all the population of the drainage area above the intake of the filter beds were sick of typhoid fever. *The number of bacteria removed by sand filtration was* 99·81 *per cent.*

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* This subject has been exhaustively treated by Lieut.-Colonel Moore in his *Sanitary Engineering Notes*. Those interested should read a paper by W. R. Maguire published in *The Transactions of the Sanitary Institute*, Vol. XIII., p. 168. From this it will be seen that the "reproach of typhoid" is by no means confined to barracks.

† The information here given has been obtained from a paper by George W. Fuller, biologist in charge of the Lawrence Station, read at the Montreal meeting of the American Public Health Association, 25th September, 1894.

The annual death-rate from typhoid fever in Lawrence before the establishment of filtration was 1·27 per 1,000, or 63 actual deaths in a present population of 50,000. During 1893, *i.e.*, subsequent to the establishment of filtration, there were 26 deaths, of which 12 were known to have drunk polluted canal water.

We conclude, therefore, from these experiments, and from others of a similar character, that it is possible and practicable to protect the consumers of an infected water supply from cholera and typhoid *by means of proper sand filtration.*

Further, it is necessary to see that in regard to fittings of all kinds scrupulous cleanliness is insisted on. Cisterns, service reservoirs, pipes, domestic filters, and water vessels must, obviously, not be in themselves centres of pollution. The precautions in each of these cases will be separately dealt with.

Given these conditions, we may fairly expect that the reproach of typhoid fever will be removed, or at least much reduced, in our cantonments and barracks.

EXAMINATION OF WATER.

The following are brief notes* on the subject of water examination and analysis as far as that subject concerns the engineer. The points to which attention should be directed are :—(1). Colour. (2). Turbidity. (3). Taste. (4). Odour.

As regards *colour*, the water should be examined by looking at a white surface vertically through at least 2 feet of depth. Pure waters have a bluish tint. Green denotes a suspicion of vegetable contamination. Brown or yellow may indicate sewage, but may be the result of peat or salts of iron.

Clear waters are, as a rule, pure, but polluted water may sometimes have this characteristic.

Polluted waters have sometimes a disagreeable *taste*, but this is not an invariable rule. Iron can be tasted, but other salts are not recognizable unless they are present in large quantities. Of course, it may not be wise to taste a suspicious water.

If water be warmed in a flask or kettle and the vapour *smelt*, the presence of gases, such as sulphuretted hydrogen or others indicative of putrefaction, may be detected.

In a water full of matter, organic or inorganic, in suspension, which has been left for some days, the solid particles will sink to the bottom, and may give valuable evidence as to the source of supply under microscopical examination.

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* From Dr. Louis Parkes' *Hygiene*, p. 78.

If the sediment exhibits signs of refuse mingled with living organisms, the inference is that the water has been contaminated with sewage.

The chemical examination of water is carried out by experts. It is necessary, however, for the engineer to know how to collect samples for submission to the chemist, and what interpretation to put on the analysis after it has been made.

For collecting samples* for chemical analysis, the glass-stoppered bottles known as "Winchester Quart," containing rather more than half a gallon, should be used. They should be thoroughly cleaned at first with a little acid, and then rinsed with the water to be collected three or four times before actually filling with the sample. The quantity usually required is half a gallon. The sample should be a fair specimen of the water, *e.g.*, in pumping from a well the water should be pumped for a few minutes, so as to empty the barrel of what was standing in it originally, or in a river the sample should not be taken near the bank, also noting whether there has been a heavy rainfall or previous drought. In a town supply it should be taken direct from the mains, or if taken from a house-tap, the water should be allowed to run some time before collecting. The bottle should be filled almost to the neck, stoppered, and the stopper covered over with a piece of clean calico, washleather, or gutta-percha tissue, tied and sealed. No luting should be used round the stopper; if it does not fit tight, use a clean cork. If the water evidently contains organic matter, the examination should be made as soon as possible, within 48 hours at most, after collection. A "tie-on" luggage label, with description of the sample and the date, should be affixed at once to the neck of the vessel and sealed. Adhesive labels should not be used. When the sample is taken, it should be kept in a dark, cool place until required. In sending a sample for analysis, any information obtainable regarding geological situation, source and possible causes of pollution, should be forwarded in an accompanying report.

As regards the interpretation of the analysis when obtained, probably the best plan will be to give a few samples of analyses of various waters, and then comment on the points of difference.

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* See Appendix 37—Regulations for Army Medical Services—issued with A O. dated 1st June, 1895.

Analysis of Water in Parts per 100,000.

	Source.	Total Solid Impurity.	Organic Carbon.*	Organic Nitrogen.*	Ammonia.*	Nitrogen as Nitrites, and Nitrates.	Total combined Nitrogen.	Chlorine.	Hardness.		Remarks.
									Tem-porary.	Perma-nent.	
I.	Upland water, *e.g.*, Thirlmere.	2·66	·194	·001	·003	·002	·008	·52	0	·7	Clear and colourless.
II.	Deep well in chalk 200′ deep.	36·52	·030	·009	·0	·582	·591	2·40	20·	7·9	Clear and good.
III.	Shallow well	65·76	·249	·096	·165	1·70	1·939	5·18	22·9	14·8	Very turbid.
IV.	Spring from gravel over London clay.	154·7	·176	·057	·001	7·395	7·453	27·5	18·9	34·1	Clear and palatable.
V.	Land drainage water from sewage farm.	64·02	·982	·191	·388	·756	1·26	6·36	17·5	15·4	

* The organic carbon and nitrogen are often left undetermined. The process is difficult and complex, and is now generally held to give unsatisfactory results. "It is desirable, however, to have some knowledge of the manner in which the results are stated, chiefly because the analyses in the Reports of the Rivers Pollution Commissioners—the most interesting and exhaustive report on Water Supply ever compiled—were conducted by this process."—*Parkes.*

It has been mentioned above that what is of greatest importance in the sanitary value of a water is the *organic* matter, and more especially the quality of that organic matter, *i.e.*, whether chiefly vegetable or animal. It is very difficult to determine this important point by any method of analysis, and at first sight it would appear that analyses such as those shown above do not help us in any way. But chemical science does assist in this respect very materially, enabling us, by examination of the analysis and comparison of the existing proportions of the various ingredients, to draw valuable conclusions.

Thus an important matter is the ratio of nitrogen to carbon in the organic matter. If the organic matter is mainly of a vegetable, and, therefore, comparatively harmless, origin, as in a peaty water, the ratio will be low. Thus in the above table Sample I. gives a ratio of $\frac{1}{48}$, II. gives $\frac{1}{3\cdot3}$, III. gives $\frac{}{2\cdot6}$, IV. gives $\frac{}{3\cdot1}$, V. gives $\frac{1}{5\cdot1}$. The Rivers Pollution Commissioners stated that good drinking water should not contain more than 0·2 parts of organic carbon and 0·02 parts of organic nitrogen per 100,000. The ratio for drinking water should not be more than $\frac{1}{6}$ or $\frac{1}{7}$.

Animal matter contains a much higher proportion of nitrogen to carbon than vegetable matter does* ; hence a water which has these quantities in high proportion is suspicious. Judged by this standard, No. I. sample above is the only one quite free from suspicion.

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* See Thorpe's *Dictionary of Applied Chemistry*, Vol. III., p. 965.

Ammonia, generally sub-divided into *free* and *albumenoid* ammonia, is generally also regarded as an indication of animal organic matter. It is true that a few pure deep well waters contain excess of ammonia, but they are remarkably free from organic matters. In the samples given above, it will be seen that III., a shallow well (which has the worst ratio of carbon to nitrogen), has ·165 parts of ammonia, and that V., land water from a sewage farm, has ·388, while the pure water of Thirlmere (I.) has ·003, and from a deep chalk well (II.) there is none discernible.

The importance of albumenoid ammonia is that it not only affords an index of animal matter, but it is *removable by filtration.* Hence the efficiency of various forms of filters can be compared by noting the quantity of albumenoid ammonia in the analyses before and after filtration in each case.

Nitrates and nitrites "are the oxidized residues of organic matters, possibly derived from an animal source."* They indicate, therefore, pollution of the water at some period. In deep well or spring waters they indicate merely the complete purification which the water has undergone by natural filtration. In the case of shallow water, if found in conjunction with chlorine and ammonia, they indicate soakage of sewage or refuse into the well. Thus in the samples quoted, No. IV. has a large quantity (7·395 parts), and although it is not in conjunction with ammonia, the quantity of chlorine, viz., 27·5, indicates pollution. No. III. also indicates by its quantity (1·70 parts together with ·165 of ammonia and chlorine) a dangerous quality of water.

Chlorine is quite innocuous by itself, but it is very important also as indicating animal pollution. In unpolluted upland surface water there are at most about 1·5 parts in 100,000, whereas sewage has 10·6 parts. Chlorine is not an absolute proof of sewage contamination, but is valuable as a confirmatory test, as will be seen from examination of the samples given in the table above. *It is not affected by filtration.*

A chemical test of the quality of a water should be, therefore, regarded in the light of the above facts. It should be further tested from a biological point of view, to ascertain the number of micro-organisms existing in it. The collection of samples for bacteriological test would probably be much the same as for the chemical test. The method of conducting the biological test would not form one of the duties of the engineers. It is sufficient here to say that while chemical analysis affords us a guide as to the general character of the water, the bacteriological test will give information regarding specific diseases.

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* Parkes.

Professor Ray Lankester, in a series of lectures in 1895 at the Royal Institution, has given some important information regarding bacteria in water. The typhoid and cholera organisms would live in very pure water, even in distilled water. The ordinary non-poisonous bacteria which live in natural water are very active and vigorous, and very hostile to the typhoid bacteria. If the latter be introduced into ordinary river water it would be destroyed very quickly by the "friendly microbes," whereas it would live in distilled water. Hence the inference is that river water is healthier than that taken from a pure spring or lake—water in which the typhoid bacteria could flourish.

Further facts with regard to filtration mentioned by this great authority will be subsequently alluded to.

HARDNESS.

Water is said to be *hard* or *soft* when it decomposes a greater or less quantity of soap before forming a lather. It is chiefly due to carbonates of lime or magnesia, these substances forming "temporary" hardness. These carbonates are kept in solution by the carbonic acid present in the water; but when this is driven off in boiling, the chalk or carbonate of lime no longer remains dissolved, but is precipitated on the sides of the vessel containing the water. This is the reason of the "furring" or incrustation of kettles and boilers. Another method of getting rid of the temporary hardness is by *adding* lime water to the water, and thus, by an apparent paradox, get rid of a lime salt by adding more lime. How this is done on a large scale will be shown presently when treating of actual details.

"Permanent" hardness is that which cannot be removed by boiling or any process. Granite, gneiss, mica, slate and some sandstones produce soft water, while hard water is found in limestone, new red sandstone, oolite, chalk, and some of the tertiaries.*

The disadvantages of hard water are chiefly with regard to waste of soap in washing, although it is not so good for cooking as soft. It is not necessarily unwholesome for drinking, although for horses it is not so good as soft water. Hence, in barracks, it is customary to utilize rain water, which is very soft, from roofs for washing purposes, and have a separate supply for drinking (see Chapter X.).

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* *Suggestions for Improving Indian Stations*, Army Sanitary Commission, 1882.

The relative hardness of water is calculated on what is known as Clark's scale, 1 grain of carbonate of lime per gallon being the unit. Thus water of 10° hardness will waste as much soap as would be wasted by pure water with 10 grains of chalk per gallon added to it. Now as every grain of chalk wastes 8 grains of soap, every gallon of water at 10° hardness will waste 80 grains of soap. Thus if every person uses 6 gallons of such water per diem, this means 480 grains of soap per diem, or 25lbs. of soap per annum, wasted.

The saving in Glasgow resulting from the use of soft Loch Katrine water has been estimated at £36,000 per annum.

An ordinary good water should not have more than 15° total hardness and 5° permanent hardness. Average London water is said to contain 15° of hardness, Edinburgh water 5°, Glasgow 0·8°, Manchester 1·8°, and Liverpool 2° to 3°. Soft water is by some supposed to be less healthy than hard, but the statistics of the towns above mentioned do not support this idea.

The method of estimating the hardness varies in different countries. In France each degree of hardness indicates 1 part by weight of carbonate of lime per 100,000 parts of water; in Germany 1 part of lime per 100,000 of water. Thus 1 English degree = 0·8 German = 1·4 French. The French scale is commonly used among analysts.

Hard water is said to be objectionable for cooking, as the lime tends to harden the fibre of meat when boiled; and it is also said to take longer than soft water for the infusion of tea. On the other hand, the tea is said to be better in flavour with hard water.

In laundry work the use of soda neutralizes the effect of hardness, as the soda (carbonate of sodium) precipitates the calcium salts and prevents the destruction of the soap.

The removal of hardness will be subsequently considered, in treating of the details of purification.

METALLIC POLLUTION.

The metals which have been found in water are for the most part iron, zinc, and lead. Other metals may be also found, but not in ordinary cases.

Iron is not poisonous, but has an unpleasant taste and colour. It stains linen in washing and is, therefore, not to be used if any better quality can be obtained. The Massachusetts experiments, too, have shown* that when a ground water contains in solution 0·5 parts of iron per 1,000,000 parts, a precipitate will generally settle when the water stands exposed to the sun. At Charlottenburg, in Germany, where the proportion is 0·2 parts per 1,000,000, special filtering works have been erected, and have been most successful in removing the iron. The water is first passed through about 10 feet thickness of coke at the rate of 127 gallons per square foot per hour, then through a second filter at 25 gallons.

Another objection to iron in water is that, where organic impurity also exists, the conditions are most favourable to the growth of a certain fungus which multiplies with astonishing rapidity, rendering in some cases filters useless.

A case of removal of iron in connection with a military water supply is mentioned† as having taken place at the infantry barracks at Aurich, in East Friedland. The amount of iron was 1·12 grains per gallon. The water was broken up into numerous small streams by pouring it through perforated plates over a column of coke about 10 feet high, 6½ feet long, and 3¼ feet broad. It was then filtered through sand. The coke becomes encrusted with iron deposit, and is periodically cleansed. The water was practically purified of all iron by this process.

Zinc gives indication of its presence in a water by a disagreeable taste. It has an injurious effect on the health. The use of galvanized iron receptacles for water has made pollution by zinc (galvanized iron being merely iron coated with zinc) a possible source of danger, and water ought not to be allowed to stand long in such vessels as galvanized iron cisterns.

Lead is a very poisonous metal, and its effects are much more dangerous than those of zinc. Professor Wanklyn considers $\frac{1}{10}$ of a grain per gallon the utmost safe limit. The symptoms of lead poisoning are colic, palsy, and a blue line along the gums. Cisterns and pipes of lead are, therefore, not to be recommended. Pure, soft waters sometimes are much affected by lead (although this has not been the case with the Loch Katrine water); but waters containing carbonates form a crust on the surface of the metal, protecting it from corrosion.

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* Report, 1892–93.

† *Engineering Record*, 17th November, 1894.

SUMMARY OF QUALITIES OF WATER.

From the foregoing we may obtain, before going on to consider in detail practical questions of purification, the following summary of the conditions of purity in a water:—

1. All water has a certain amount of solid matter in solution, and although the quantity is not an absolute guide to its being a good drinking water, those waters are generally the most wholesome which are purest.

2. Animal organic matter is the most dangerous of all impurities in a water.

3. Nature provides in the current of streams a means of purification varying with velocity, depth, temperature, etc.

4. Animal organisms can be removed from water by efficient filtration.

5. In examining water generally, colour, taste, smell and clearness should be carefully noted.

6. In collecting samples for chemical analysis much care should be taken to avoid external sources of contamination in the sample.

7. In chemical analysis the organic animal impurities present are shown by (*a*) the ratio of nitrogen to carbon*; (*b*), the amount of free and albumenoid ammonia; (*c*), the nitrites and nitrates in conjunction with chlorine and ammonia; and (*d*) the quantity of chlorine.

8. Hardness affects water for washing and cooking, but not generally as regards wholesomeness for drinking.

9. Hardness may be removed by the addition of lime water.

10. Iron in water may be removed by filtration through coke and sand.

11. Lead and zinc both affect water so as to make it poisonous to a great extent, the former especially so. Lead pipes and cisterns may be used with a hard but not a soft water.

PURIFICATION OF WATER.

Water may be purified by (*a*) subsidence; (*b*), æration; (*c*), filtration; (*d*), precipitation.

Subsidence is a process of settlement of the solid matters held in suspension, those of heavier specific gravity than the water falling to the bottom with a rapidity depending on the fineness of the particles and the amount of the specific gravity, and the lighter particles rising to form a scum on the top. This action is continually going on in all reservoirs, and it is necessary, therefore, where there is much suspended matter in a water, to provide *settling tanks*, where the water may lie tranquil for some time, and issue in a comparatively pure stream. A well-known instance of this action in Nature is the Rhone, which enters the Lake of Geneva in a turbid stream, deposits its suspended matter at the bottom of the lake, and issues in a clear blue current. These settling tanks or reservoirs should be from 12 feet to 16 feet deep. The number will vary with circumstances, but in most cases there should be at least two, so that one may be emptied while the other is being used. There are two systems of arrangement of these settling tanks, one the *constant* settlement, where water is continually passing, and the *intermittent*, where, with several tanks, one may be in the process of being filled, others may be quiescent, and others may be emptying. The former system is considered by Professor Burton to be the best.

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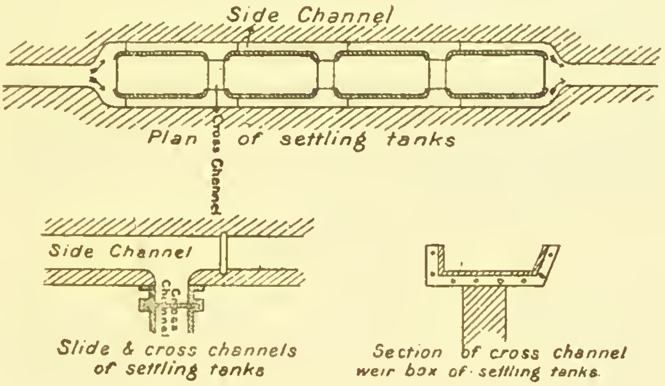
* When these are determined, which is seldom done.

The plan of such tanks is usually rectangular (see *Fig.* 60) with the longer side in direction of the flow; in section the floor should have a slight slope of about 1 in 200 towards a central drain, which has also a longitudinal slope of about 1 in 200 or 300 towards one end, to facilitate cleansing. When the draining of the tank by gravity is impossible, it will be necessary to provide a pump to clean it. The sides may be either sloping or vertical, the latter for preference.* The settling tanks should be open to the sunlight, which is a most powerful germicide.



Plan of settling tanks

Slide & cross channels of settling tanks

Section of cross channel weir box of settling tanks

Fig. 60.

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* Professor Burton, *Water Supply of Towns*, pp. 88 *et seq.*

As regards materials for construction, puddle may be used, but if good cement is obtainable, concrete should be preferred.

The positions of the inlet and outlet pipes is of much importance, and in considering the best arrangement it is advisable to take into account the temperature of the water. If the incoming water is warmer than that in the reservoir it will tend to rise to the top, and *vice versa.* The subject is fully discussed by Professor Burton,* who concludes that the position for best settlement is when the *inlet is at the bottom* of the tank and the *outlet near the top.* This will give the best possible settlement if the incoming water is relatively cold, and a good settlement if it is relatively warm. A movable shutter may be provided to alter the arrangements for winter and summer use (see *Figs.* 61 and 62). The form of the inlet

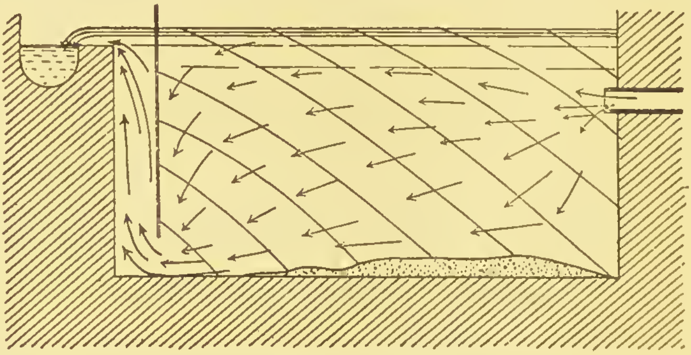

Fig. 61 (*Summer*).

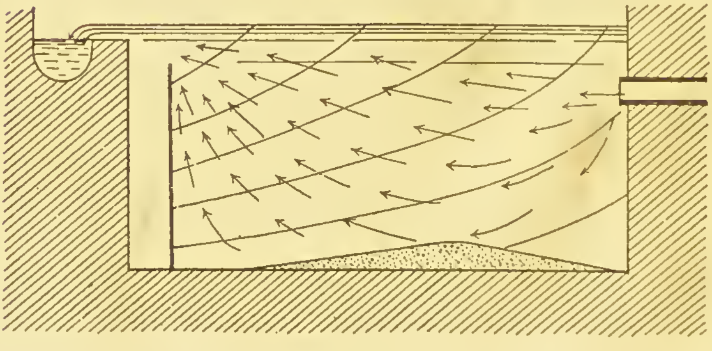

Fig. 62 (*Winter*).

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* From whose book *Figs.* 60, 63 and 64 have been copied by permission of the publishers.

should be a bell mouth pointing upwards (see *Fig.* 63). A drain or scouring pipe, and an overflow pipe, should also be provided, and a draw-off pipe (see *Fig.* 64).

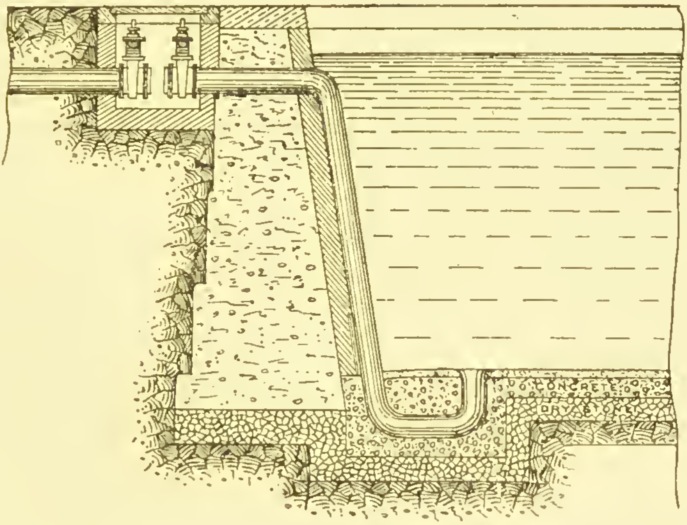

Fig. 63.

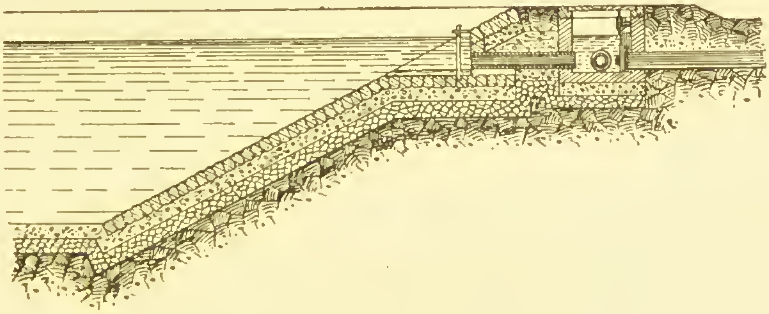

Fig. 64.

Plate XXIX.* shows the general arrangement at the Shanghai waterworks.

Æration consists, as its name implies, in bringing to bear upon the particles of water the oxidizing action of the atmosphere. It is not frequently employed. The water is broken up into thin sheets of spray in the manner described above as adopted in the barracks at Aurich, the result being to liberate such impurities as sulphuretted hydrogen and carbonate of lime. With distilled water some method of æration is desirable to prevent its taste being flat and insipid. Æration sometimes has the effect of removing bad odour and discolouration in water,* as well as preventing stagnation and checking the growth of algæ. In some cases water in tanks is ærated by air being forced through perforated pipes placed inside the tanks.

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* From *Minutes of Proceedings, Institution of Civil Engineers*, Vol. C. As the source of supply is a tidal river, the purifying arrangements are necessarily elaborate, and are therefore given as a type.

FILTRATION.

We now come to the subject of *filtration*, a process which is necessary in almost every water supply, and which has acquired the greater importance in the light of the biological discoveries of modern times in England, Germany and America, previously alluded to. It is not safe to leave this to private individuals. Professor Ray Lankester, indeed, is of opinion that *domestic filters are a means, not of destroying, but of communicating bacteria* to water, and he states that a domestic filter in use for a week has been found to contain as many as 200,000 bacteria per cubic centimètre. On the other hand, with large sand filters the bacteria become on the lower layers of sand a jelly,† through which the water has to pass, carrying with it neither solid particles nor poisonous germs.

The action of a sand filter upon water is not merely that of a sieve, which arrests particles larger than the interstices and allows others to pass. On the contrary, all the exposed surfaces of the sand particles have an efficient value, insomuch that they would be found, if examined after use, to be coated with the removed impurities equally all over. We can, therefore, at once understand that the velocity at which the water passes through the filtering medium is a matter of much importance, and this will be modified by other circumstances, such as the purity of the water, the coarseness of the sand, and the temperature. Professor Burton considers that a maximum speed of 10 feet in 24 hours, or 2,722,500 gallons per acre, is permissible with good water.

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* See *Engineering Record*, 10th June, 1893, p. 20.

† This "jelly" explains a fact which for some time had puzzled waterworks managers. They knew as a fact that they could satisfactorily filter water through sand which had been partially clogged, whereas they could not do so with perfectly clean sand. The researches of eminent bacteriologists have tended to prove that the purification of water is largely due to the omnivorous activity of living organisms. It is only when a filter bed is literally alive with micro-organisms that prey upon organic impurities, that its action is really efficient. The maintenance of the filter bed in a proper condition for the nourishment of these "friendly microbes" appears to be the goal to which science would now point.

Mr. Allen Hazen, the chemist in charge of the experiment station at Lawrence, Mass., previously alluded to, found that the quantity that would flow through the sands ordinarily used for filtration would be, at a constant temperature, directly proportional to the depth through the sand. He also found it directly proportional to the acting head and inversely proportional to the depth through the sand. He also found it directly proportional to the square of the maximum diameter of the finer 10 per cent. of the sand grains. Calling the maximum diameter in millimètres d, the head in feet h, the distance flowing through the sand l, and quantity passing, expressed in million gallons per acre per 24 hours, Q, he found the following formula to satisfactorily express the results of his experiments with water about 50° Fahr.:—

$$Q = \frac{800\,hd^2}{l}$$

From this formula it will be seen that the measurement of the grains of sand is of great importance. The method of doing so is as follows:—

Determination of the Sizes of the Sand Grains.

The sizes of the sand grains can be determined in either of two ways: from the weight of the particles, or from micrometer measurements. For convenience, the size of each particle is considered to be the diameter of a sphere of equal volume. When the weight and specific gravity of a particle are known, the diameter can be readily calculated. The volume of a sphere is $\frac{1}{6}\pi d^3$, and is also equal to the weight divided by the specific gravity. With the Lawrence materials the specific gravity is uniformly 2·65 within very narrow limits, and we have $\frac{w}{2\cdot65} = \frac{1}{6}\pi d^3$. Solving for d, we obtain the formulæ $d = \cdot9\sqrt[3]{w}$ when d is the diameter of a particle in millimètres and w its weight in milligrams. As the average weight of particles, when not too small, can be determined with precision, this method is very accurate, and altogether the most satisfactory for particles above 0·10 millimètre, that is, for all sieve separations. For the finer particles the method is inapplicable, on account of the vast number of particles to be counted in the smallest portion which can be accurately weighed, and in these cases the sizes are determined by micrometer measurements. As the sand grains are not spherical or even regular in shape, considerable care is required to ascertain the true mean diameter. The most accurate method is to measure the long diameter and the middle diameter at right angles to it, as seen by a microscope. The short diameter is obtained by a micrometer screw, focussing first upon the glass upon which the particle rests, and then upon the highest point to be found. The mean diameter is then the cube root of the product of the three observed diameters. The middle diameter is usually about equal to the mean diameter, and can generally be used for it, avoiding the troublesome measurement of the short diameters.

The sand* which gave the most favourable results at the Lawrence experiments had a diameter of 2 millimètres or $\frac{8}{1000}$ of an inch, a sand, in fact, such as one might fairly use for good building work. Such a sand, with a 1-foot head of water and a thickness of 6 feet, could thoroughly cleanse 4,300,000 gallons per acre per 24 hours when clean. Generally, American practice points to the conclusion that river water may be filtered through proper materials, efficiently, at rates of from 4 to 8 million gallons per 24 hours per acre, an amount considerably in excess of Professor Burton's estimate.†

The depth of the sand may be from 2 feet to 5 feet, 3 feet may be taken as a standard thickness. Professor Frankland considers that the water should be left for 12 hours undisturbed before filtration is commenced, and that the filtrate obtained during the first 24 hours should not be supplied for consumption.

The total area of the filter beds will depend on the results of the calculation above mentioned as to the quantity and speed of filtering. If a be the required area, and f the speed in feet, while $Q =$ quantity consumed in one day in cubic feet, then $a = \frac{Q}{f}$ in square feet.‡ The velocity of flow should not exceed 3·9 inches per hour (Professor Notter).

The number of the filter beds will vary with the available site.

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* Extract from a paper by Hiram F. Mills, read at the Columbian Exposition.

† In a book recently published, *The Filtration of Public Water Supplies*, by Mr. Allen Hazen, the author is of opinion that it is safest not to exceed 2,570,000 gallons per acre. This is the limit prescribed by German law.

‡ Burton.

It is found advisable to give a limiting breadth of about 16 feet, as a man can, walking down the centre, cover the whole of that breadth with a long-handled broom, brushing the upper layer of sand.

When the velocity of the water is kept within moderate bounds the sand is not liable to be washed away ; hence a gradation of materials, beginning with boulders and ending with sand, is not necessary.

The floor of the filter bed should be of concrete, and water-tight. Over the floor there should be a cellular brick floor of one of the forms shown in *Figs.* 65 and 66 down the centre of the filter bed, with branch drains of stoneware at a maximum distance of 6 feet apart, above these again 6 inches of gravel. *Fig.* 66 shows an adjustable outlet.

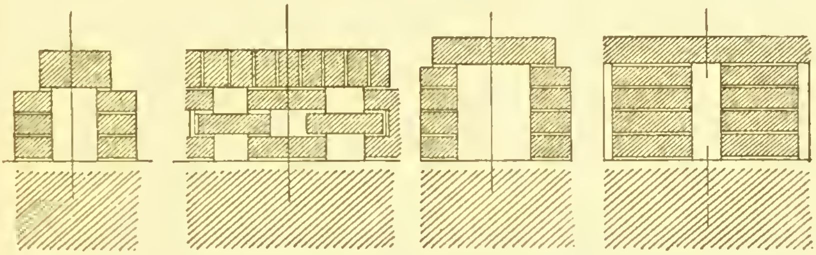

Fig. 65.

The depth of the water above the sand may be about 3 feet. In variable climates deep filter beds are best, so as to have in winter sufficient water to resist for some time the attacks of frost. When ice forms, the edge of the tank should be kept open so as to reduce the thrust of the ice on the sides. Deep filter beds keep the water cool in summer, but are liable to stagnation.

* A plan and section of part of a filter bed is shown in *Fig.* 67, *Fig.* 68 showing connection with valve or clean water well.

The sides of a filter bed may be either vertical or sloping.

The "filtering head," alluded to above, is the difference in level between the clean water well and that in the filter bed. It is the head of water necessary to overcome the friction in the sand and draining arrangement.

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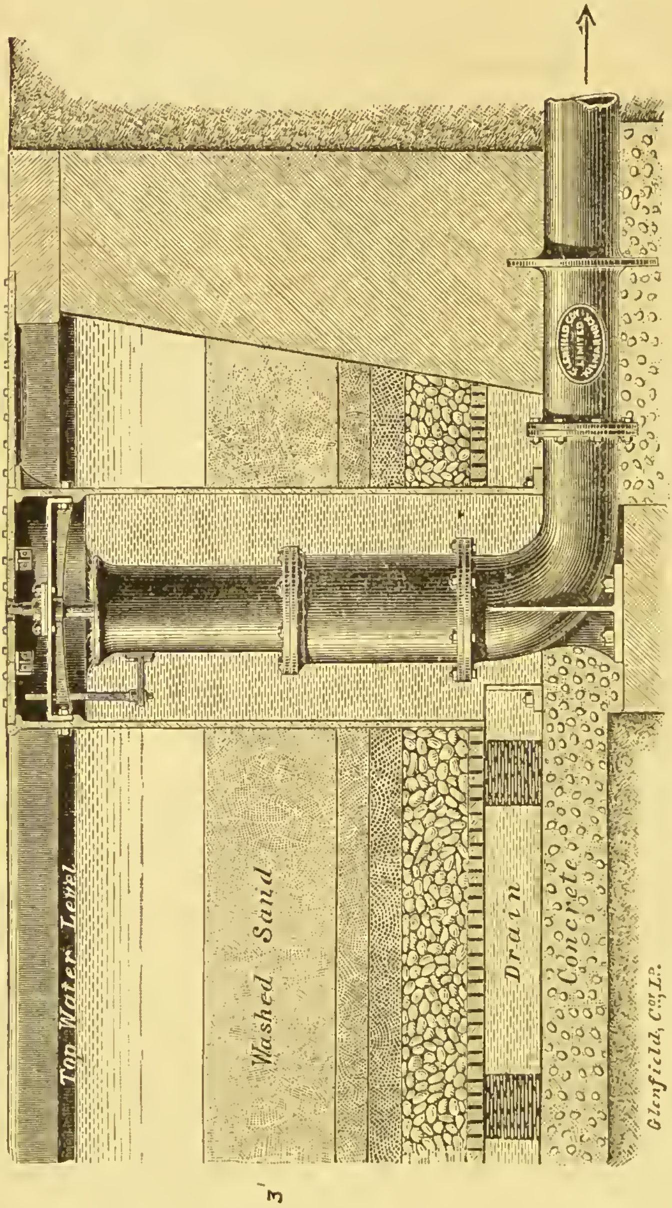
* *Figs.* 61, 62, 65, 67, 68 and 69 are adapted from illustrations in Herr Lueger's *Wasserversorgung der Städte.*

It requires no great reasoning or knowledge of hydraulics to see that, in order to keep this head and the velocity of the water at a uniform condition, there must be some means of regulating. In *Figs.* 66 and 67 this regulation is effected by means of valves on the pipe leading from the filter to the pure water well. This arrange-



Filtering material 3' 0" washed sand
0' 3" coarse sand (small shot)
0' 3" fine sand (peas)
0' 6" coarse gravel (walnuts).
Level of Outlet pipe adjustable by screw worked from above.

Fig 66.

ment, though common, is manifestly irregular, and, therefore, imperfect. The difficulty thus caused can be overcome by several

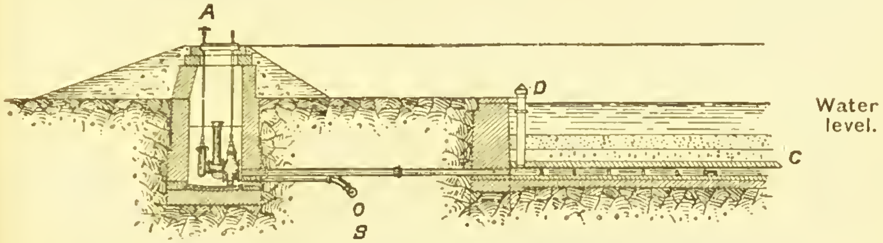
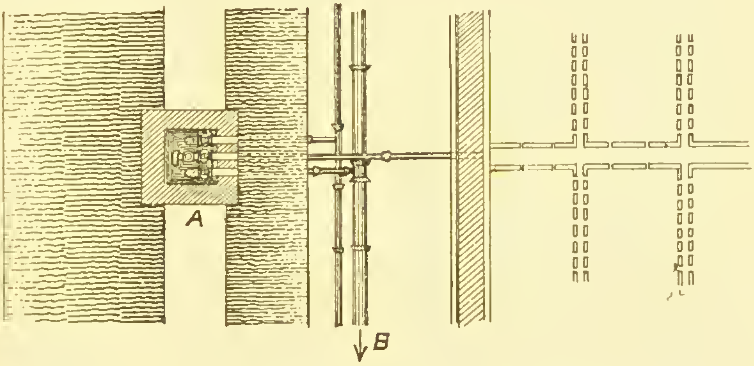


Fig. 67.



A. Outlet well and valves.
B. Outlet pipe to clean water reservoir.
C. Filter, 3′ 6″ thick, in two layers of sand of varying coarseness.
D. Ventilating pipe.

Fig. 68.

arrangements fully described by Professor Burton, whose observations on this subject are the result of much practical experience.

One of these is described by General A. de C. Scott, R.E. (*Minutes of Proceedings of Institution of Civil Engineers*, Vol. C., 1890). The arrangement, as described, is carried out in Berlin by Mr. Gill, chief engineer in charge of the waterworks of that city. Three small chambers (A, B, C, *Fig.* 69) are constructed so that A abuts against the outside of the filter, and the others follow in regular sequence. A pipe *p* enters the filter just above the sand, and its other end passes into A, and is open in a "regulating chamber" above A, B and C. The height of the water in *p* can be read on the graduated arm and attached to the float *f*. The filtered water passes through the aperture *o* into the chamber A, and through the sluice shutter *s* (which can be opened or closed at will) into chamber

B. Between B and C the connection is by a rectangular orifice with a metal plate *m*. There is another connection, governed by a sluice valve *s′*, which is used for emptying and cleansing the chambers, and there is a similar sluice valve *s″* in C. The whole object is to obtain a constant discharge over the metal at *m*, and this is secured by the action of the shutter at the bottom of chamber A, regulated by the readings of the gauge rods and floats in A and B. As the filter becomes gradually foul, and the flow checked, the valve at A is adjusted so as to increase the opening into B and keep up the charge on the metal plate. This gives also a greater head on the filter, so as to maintain the normal rate of flow through the sand. When the level at A falls to that at B, the filter requires cleaning, and the supply is shut off. The regulation is carried out with ease and certainty.

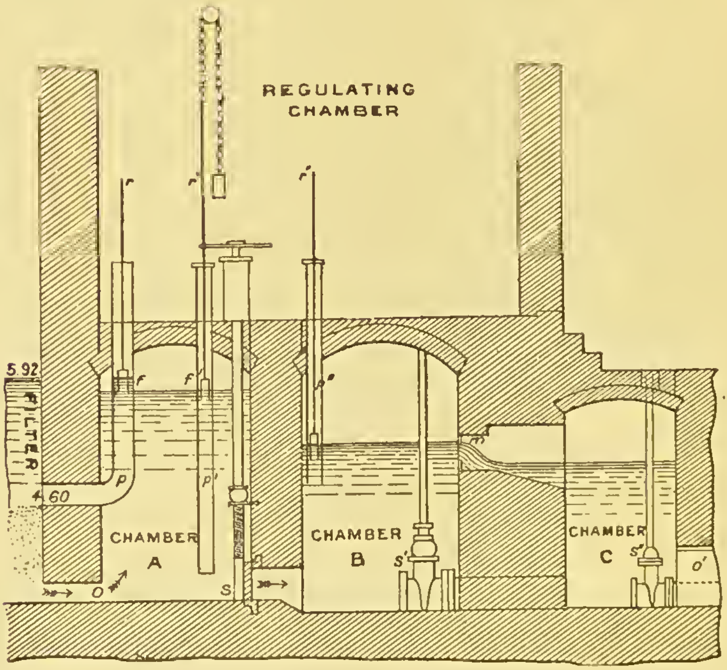


Fig. 69.

Fig. 70* shows another automatic arrangement of a comparatively simple nature. There the water pours over orifices of a given size in the sides of the outflow pipe, which is telescopic below, and fastened to a cross-beam attached to floats, so that the orifices are always kept at the surface of the water. This ingenious arrangement has been adopted at Warsaw. It will be evident that the efficient working of this arrangement consists in the joint where the one pipe slides on the other being water-tight. Other arrangements, differing in details, but on the same principles, are shown in *Fig.* 71.

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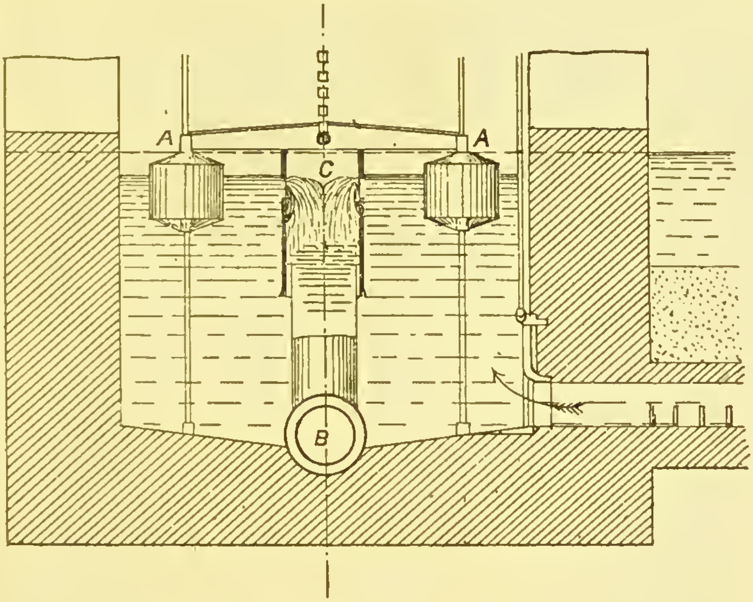
* Lueger's *Wasserversorgung der Städte*, p. 434.



A.A. Floats.
B. Outlet pipe.
C. Adjustable overflow, to outlet.

Fig. 70.

Another automatic regulator on the principle—well known in connection with gas regulators of volume—of producing a constant discharge by the flow passing through a small opening in a movable thin plate has been invented by Professor Burton, and applied by him to various waterworks in Japan.* *Plates* XXXVIII. and XXXIX. show plans and sections of filter beds and receivers. These are not of the latest type, but will serve as guides in design.

At first starting, filters should be filled from below with filtered water from other beds, until the whole is covered to a depth of 2 or 3 inches. Unfiltered water may then be introduced. If the filter bed is not filled from below first, there is no means of controlling the filtering speed. Where there are three or four filter beds communicating with a clean water tank, arrangements for supply of filtered water below to any one of these can easily be made and governed by stop-valves.

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* For details, see *Water Supply of Towns*, pp. 108—110.

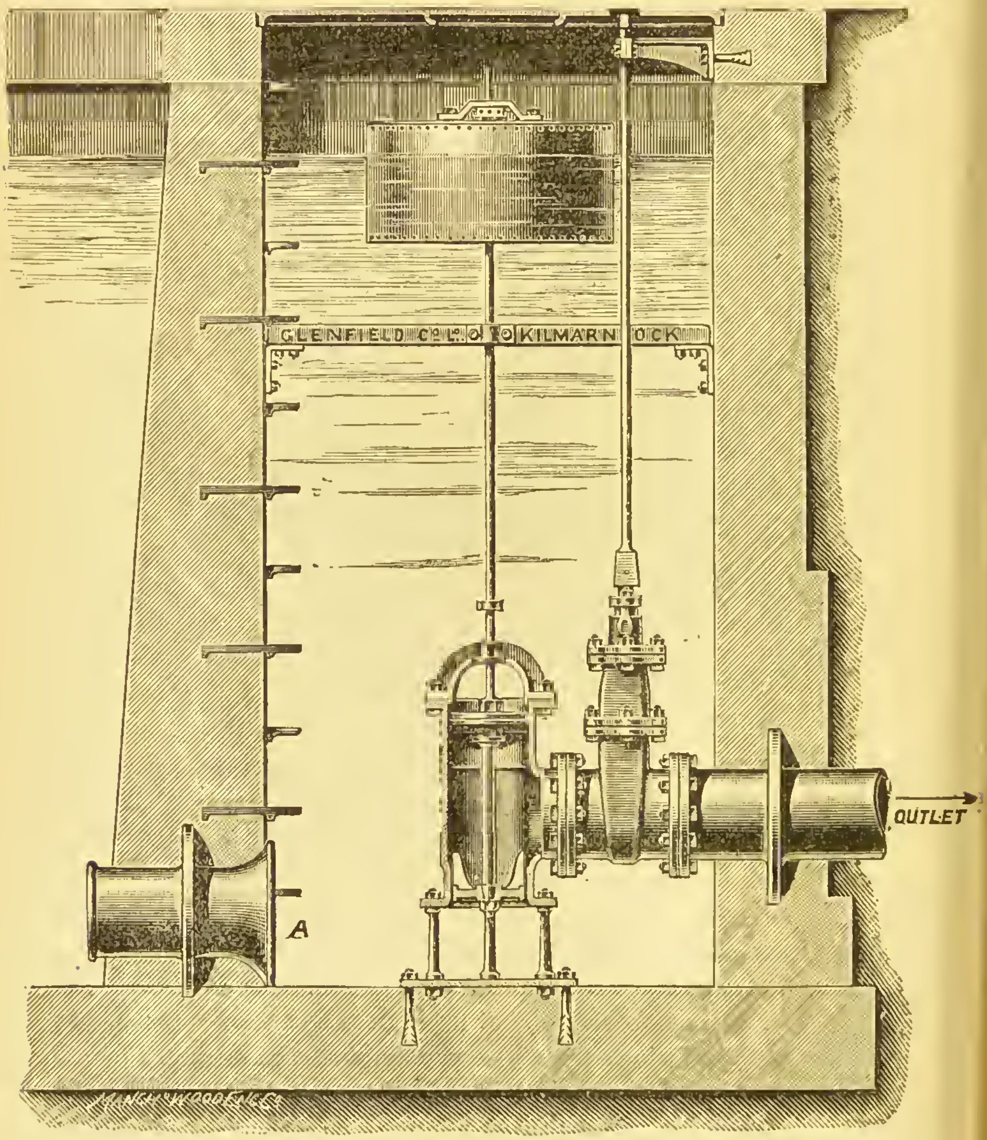
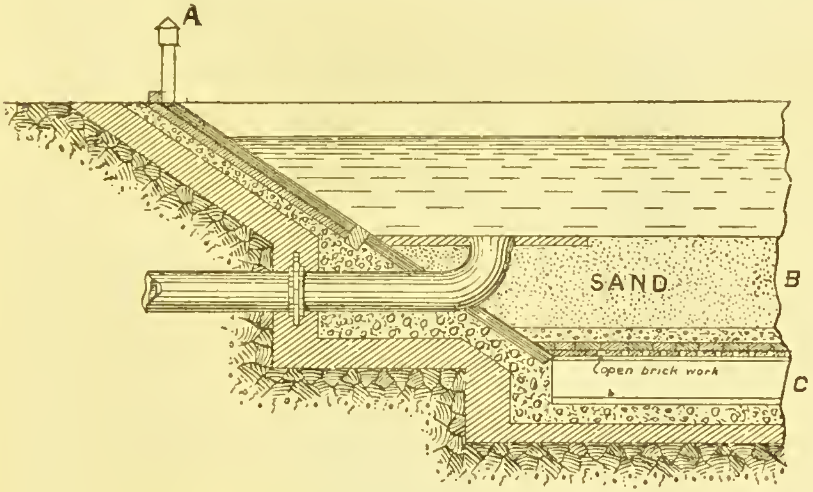


Fig. 71.

The admission of the unfiltered water to the bed must be so arranged that the sand shall not be worked away by the violence of current at the entry. The simplest method is to have the inlet pipe, terminating in a trumpet-shaped mouth, discharging upwards at the level of the sand in the filter, and with bricks or stones laid round it for a few feet (see *Figs.* 72 and 73). Another method is to have



A. Ventilating pipe.
B. Filtering material, 3′ sand over 6″ gravel (size of beans.
C. Outlet drain.

Fig. 72.

the water admitted into a channel either in the centre or sides of the filter bed and overflowing gently on to the surface of the sand.

The level of the water should be kept constant over the sand, either by sluices or automatically by a floating ball valve, as manufactured by the Glenfield Company or any other firm of water-fitting manufacturers.

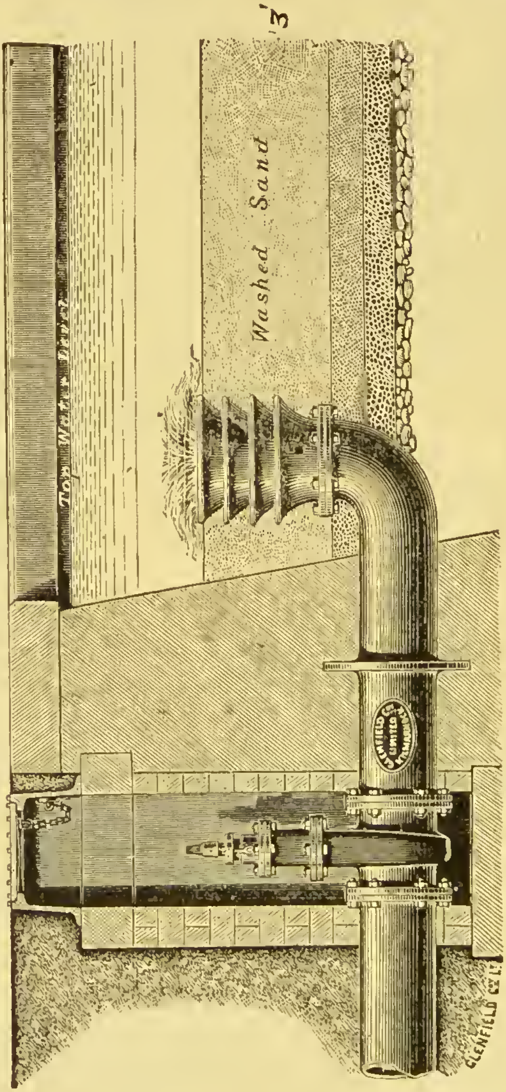
A sand filter should be kept in use as long as possible, though exact information on this point is as yet not established. The *rate* of filtration should be kept as uniform as possible, though this can only be effected by careful valve regulation.

Filtering with Substances other than Sand.

Although clean sand gives the most satisfactory results as a filtering medium, there are other substances sometimes used, which deserve a passing notice. *Animal charcoal* used to be considered very good. Later experiments have shown that it is quite unsuited for use as a filtering medium. "This cannot be too widely known, as it is still advocated in many standard works as being the best filtering material, notwithstanding the fact that recent methods of investigation have shown it to be the very reverse" (Brigade-

Surgeon-Lieut.-Colonel Notter, A.M.S., Professor of Hygiene, Netley).

Vegetable charcoal is a substance of which the value as a filtering medium is much disputed. As some eminent authorities consider it to be of less value than animal charcoal, it is evident that it is not a reliable substance.



Water 3′ deep over sand.
Sand 3′ deep over 6″ layer of gravel (peas), 6″ gravel (beans), and 6″ gravel (walnuts).

Fig 73.

Of recent years, *artificial stone* slabs have come into public use with excellent results. The stones used at Worms, in Germany, in this manner are formed from washed river sand and silicate of lime and soda. The slabs are 4 inches thick, and are made in squares 1 mètre each way, with one face slightly hollowed. The slabs are built into vertical walls, two squares being joined together with the recessed faces towards one another. It will be seen that this is, in fact, sand filtration, but the layers of sand are vertical and pressed close together, instead of being horizontal. The slabs are extremely porous. The advantages of this method as compared with sand filtration are:—(1). That it occupies much less space. (2). That it is much easier to maintain, since suspended matter, finding no lodgment on the vertical surface of the stones, sinks to the bottom of the tank, whence it is periodically flushed out. (3). It is a most efficient filtering medium, both chemically and biologically.

Spongy iron is of considerable value, though possessing no advantages over sand. Its action on water is both mechanical and chemical. Its power, however, as a purifier is much affected by oxidation. The filter beds at Antwerp, where it has been used, rusted into large concrete masses, and had to be removed.

Polarite is a black, porous, magnetic iron, insoluble in water, hard and absorbent. Its action is very similar to that of spongy iron. It is prepared by the International Water and Sewage Purification Company, Limited, and is said to purify water by oxidizing the noxious organic matters in solution, "converting them into nitric and carbonic acids, which form innocuous salts with the bases present, and so become harmless."* Polarite is recommended for use in waterworks because of the greater speed, as compared with sand, with which filtration can be carried out. An ordinary polarite bed will purify water at the rate of 700 to 1,000 gallons a square yard in 24 hours, or 3,388,000 to 4,840,000 gallons per acre. Both these are above Professor Burton's estimated account, but not greater than the American calculation for a sand filter (see ante). The "ordinary polarite bed" has at the bottom of the filter tank rows of 3-inch or 4-inch agricultural drain pipes, filled in between with coarse shingle, then a 6-inch layer of gravel, then 4 inches of coarse sand, then polarite and sand 12 inches thick, and finally fine sand 9 inches to 12 inches thick. The amount of polarite per square yard should be on an average 360lbs., but the quantity may vary with the impurity of the water to be filtered.

By a special arrangement of filter chambers devised by the International Company, the filtering speed can be increased up to 15,000 gallons per square yard. This is far in excess of anything ever achieved by any other process.

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* Pamphlet issued by the International Company.

Polarite is said not to need cleaning and renewal, though if combined with sand the latter must be cleaned periodically.

On a campaign, where bad water is only too common, and where rapid filtration is necessary, polarite would probably be useful.

Of domestic filters the only one worth considering is the Chamberland-Pasteur, which consists of a cylinder or tube of unglazed porcelain inside a glass or metal case. This filter acts mechanically, and even removes micro-organisms.

The metal case of this filter may be screwed to a service tap, when the pressure of the water will force the liquid through the pores of the porcelain at a rapid rate.

As the surface of the porcelain cylinder or tube becomes soon covered with a slimy substance (even though the water may be apparently clean when filtered) the tube should be carefully removed and brushed, or it may be washed with dilute sulphuric acid, which easily and quickly removes the coating.

"Summing up our present knowledge of the subject, we find that *charcoal* filters are entirely inoperative; recent experiments prove that bacilli from enteric and cholera cultures pass freely into the filtrate; *spongy iron* permits the free passage of bacteria, filtration only removing about 40 per cent., and that none of the more common filtering materials are capable of removing micro-organisms from water. The earthenware filters on the Chamberland-Pasteur and Berkefeld principle give, in nearly every instance, a filtrate practically free from germs."—Professor Notter.

Cleaning Filter Beds.

The upper layers of sand in a filter bed are those which most require renewal; generally an inch or two at a time is renewed, while the layers beneath are turned over with a stiff broom. If plenty of clean sand is available, the old stuff may be thrown away, but if not, a sand washer is required. In Walker's patent sand washer, water is introduced from below, escaping by a spout from above. When the water runs off clear the sand is clean, and can be tipped out of the washer. These washers are simply hoppers suspended from trunnions. They are supplied by Messrs. J. Tylor and Sons.

Another method is to put the sand in long, narrow tanks, introduce the clean water near the bottom at one end, and let it escape out at the other, raking up the sand from the lowest end to the highest, so that the cleanest water comes to the cleanest sand.

The reason why periodical renewal is necessary is that the filtration may become inconveniently slow when the upper gelatinous layer becomes too thick.

Besides this cleaning of the upper layers of a filter, the entire filter should be thoroughly cleaned out at intervals varying from six months to some years, according to the nature of the water.

REMOVAL OF HARDNESS IN WATER.*

We now pass on to consider the details of removing hardness by the addition of lime, previously alluded to. The added lime reacts chemically upon the foreign substances already in the water, forming new insoluble compounds which can be removed by filtration.

Dr. Thomas Clark was the first to patent this process—in 1841. He discovered that the hardness of water is caused by the presence of bi-carbonate of lime, consisting on an average of 9 parts by weight of lime combined with 14 parts of carbonic acid, forming a salt readily soluble in water. If 9 parts by weight of lime be added to the water, it takes from the bi-carbonate half its dose of CO_2, combining with it and forming 32 parts $CaCO_2$, composed of 18 parts of lime and 14 parts of CO_2, a salt which, being insoluble in water, is precipitated, freeing the water to a great extent from lime.

To ensure chemical action, the added lime should be presented in as finely divided a state as possible, *i.e.*, in a perfect state of solution. The proportion should be the exact amount required for the particular water to be treated.

The added substance, or lime water, should be first put into the vessel, and the hard water gradually added, because in this way there is always an excess of lime in the mixture.

So far, all the systems in general use are alike, the only difference in various processes being in the method of removing the precipitated salts. There are three ordinary methods :—(1). Precipitation in tanks, from which the clear softened water is drawn off and the tanks periodically emptied of their solid contents. (2). Porter's patent system, whereby the precipitated matter is removed by a series of filter presses. (3). Messrs. Atkins' system, wherein filter cloths on circular disks are used instead of filter presses. The objection to the first method is the space required for the necessary number of tanks. Probably a form of the second system, as described below, would be most suitable for barracks.

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* Condensed from papers by H. Law, M.Inst.C.E., in the *Transactions of the Sanitary Institute*, and W. Matthews, M.Inst.C.E., *Minutes of Proceedings of the Institution of Civil Engineers*, Vol. CVIII.

The great practical difficulty is to regulate the proportions of the softening ingredient and the original water. An excess of lime would render the water unwholesome; hence, for a drinking water, this is an important matter, although it is not desirable to remove entirely all hardness from a water, except for industrial purposes. It is difficult to accomplish the regulation of the proportions by giving two pipes of discharging capacities proportional to the desired quantities, because the pipe which supplies the softening ingredient is sure to become incrustated. The best way to ensure the proper mixture is to carry out the work in a vessel open to inspection, and measure from time to time the quantities delivered. Thus, if a water has 18° of hardness, 18ozs. of lime will be required to soften 700 gallons, because 1oz. of lime is required for every degree of hardness per 700 gallons. Further, to dissolve 1 part of lime 750 parts of water are required. Hence $750 \times 18\text{oz.} = 842\text{lbs.}$ of lime water must be added to 7,000lbs. of the hard water to soften it, or the proportion will be as 1 to 8·3.

A softening arrangement which has much come into use in various places of recent years is "Andrew Howatson's Patent," manufactured by Messrs. Thwaites Brothers, of Bradford, Yorks. The patentees claim that the advantage of this softener is that the water, being almost in a quiescent condition while under treatment, is in the most favourable state for chemical action. Further, that the whole machinery is of a very simple nature.

Plate XXXVII. shows the apparatus. A is the tank where the chemical reagents are mixed and prepared, being supplied with water from the pipe *a*, which also supplies the smaller tank B, and containing an agitating arm *b* worked by handle *e*. C is another small tank which serves to regulate or measure the quantity of the reagent, and is supplied from A by the floating pipe *f*. O is the tank where the reagent and water mix, pouring in from B and C through nozzles *h* and *g* of calculated proportional sizes. (It would possibly be an advantage if these nozzles were furnished with regulating taps). On leaving O the mixture passes by the passage E to the bottom of the clarifying tank F, and it is in E that chemical reaction takes place. On leaving E the water rises, leaving the precipitated lime at the bottom of F (whence it can be drawn off periodically by the sluice L), and passes through the filter G with strainers *ii*, which cleanses any further crystals into the clean-water reservoir K, and out by the pipe *m*.

The ball-cocks in B and C prevent any overflow or waste.

This apparatus is made in sizes from about 3 feet in diameter and 8 feet high, softening 50 gallons an hour, up to 10 feet in diameter and 21 feet high, softening 2,000 gallons an hour.

There are other applications of similar principles by the same licensees. Filters as well as softeners are manufactured by them, and are apparently used largely in France and Belgium.

The effect of the softening of the water is to remove the bacteria to a very considerable extent. It is, therefore, a valuable means of purification.

MISCELLANEOUS METHODS OF PURIFICATION.

Before concluding the subject of water purification, it may be well to mention some processes sometimes practised other than those already described.

Of recent years the so-called "electrical purification" of water has been the subject of some investigation in America. A solution of hypochlorite of soda is produced by the electrolysis of brine and added to the water to be purified. This is said to remove bad smell and taste and colour as well as bacteria. The subject, however, has hardly advanced beyond the experimental stage.

Cleaning the inside of casks containing water is said to be an effective cleanser of water. It has certainly the effect of improving the condition of the cask as a receptacle for water, though that is not saying much.

Alum has long been used by the Chinese to purify water from suspended matters. It was used with salutary effect on the water of the Indus by the 92nd Highlanders in 1868 (*Indian Medical Gazette*, August, 1869, quoted in Parkes' *Hygiene*). The quantity used should be about 6 grains per gallon.

Scrap iron has been found to be most efficient when introduced into a revolving vessel with the water to be purified. The process adopted ultimately at Antwerp, and described by Mr. Anderson (*Proceedings of the Institution of Civil Engineers*, Vol. LXXXI., p. 280), consists of three revolving cylinders 15 feet long by 5 feet diameter, supported longitudinally on hollow trunnions through which the inlet and outlet pipes pass. The process is said to soften the water as well as purify it of organic matter.

CHAPTER VII.

THEORETICAL PRINCIPLES.

The Development of the Theory of the Flow of Water in Channels.—M. Darcy's Experiments —M. Kutter's Formula.—Captain Cunningham's Experiments.—Frictional Head.—Horse-power of Pumping Engines.—Calculating Size of Conduits.—Considerations Necessary for Determining the Position of Hydrants.

It is not intended, and it would not be possible within the limits of this work, to go fully into the various hydraulic questions involved in the working out of a water-supply scheme. It will be sufficient to confine our attention to some of the main points of importance. One of the difficulties has always been the different formulæ which are to be found in text-books, many of which show a very considerable difference from one another, so that an engineer is at a loss to know which of these is reliable. It will, therefore, be advantageous briefly to sketch the development of the theory of the flow of water,* so that we may arrive at a sound conclusion as to what formula should be adopted.

At the close of the 16th century the great Galileo discovered that the terminal velocity of a heavy body falling freely was, at the end of one second, 32·2 feet, and that the velocity at any instant of time was expressed by the well-known equation

$$v = \sqrt{2gh},$$

in which the letter g represents the accelerating force of gravity. He further found that the terminal velocity of a body running down any inclined plane is equal to the velocity it would have acquired in falling down the height of the plane. From this it follows that the time such a body occupies in running down an inclined plane is

$$t = \sqrt{\frac{2l}{g \sin i}},$$

in which l is the space passed over by the body, and i the angle of the inclination of the plane.

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* These notes are obtained from a lecture by Mr. James Gale, M. Inst. C. E., the eminent engineer of the Glasgow waterworks. Mr. Gale has kindly given permission to quote from his lecture, and the subject is here treated fully at the request of several R. E. officers.

These principles seemed to Galileo to apply to the case of water flowing in channels.

Galileo died in 1642, and in the following year Torricelli, his pupil, published his scientific observations, among which, one was that water issues from an orifice in a vessel with a velocity equal to that which it would have acquired by falling from a height equal to the depth of water over the orifice, and that, therefore, water followed the same laws as falling bodies generally. The velocity of efflux can, therefore, be expressed by the same formula as that of falling bodies, viz. :—

$$v = \sqrt{2gh} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1).$$

This is the fundamental expression of all hydraulic research, and it has been proved over and over again to be true for all orifices, with certain modifications arising from friction and the resistance of the atmosphere. It is the basis on which the formulæ, in Chapter III., for the measurement of the flow over notches in weirs, have been founded.

Guglielmini, about 1690, repeated Torricelli's experiments, and having found that holes of the same size bored in the side of a vessel discharged, in equal times, quantities of water proportional to the square roots of the heads over the respective orifices, he conceived that the velocity of the several filaments of water in a stream was proportional to the square roots of their depths below the surface. He supposes that "the velocity at the bottom of the stream is everywhere greater than anywhere above it, and is least of all at the surface," and that "the velocity of the stream increases continually as the stream recedes from its source." This theory was called the "parabolic theory," and was made by him and others the basis of a complete theory of hydraulics. That such a theory could be entertained by many eminent men seems incredible. A moment's consideration ought to have shown that these supposed holes were discharging under water and not freely into the air.

But a more pernicious assumption still was that by Grandi, who, at the close of the 17th century, assumed, *without any proof whatever*, "that the resistance of the banks of a river terminates at those parts which slide near them without extending to the other parts in the middle;" and conceiving a line to be drawn along the summits of the highest parts of the bottom, he was of opinion that the waters above that line cannot experience any impediment from the other waters, which lie dormant below in the hollows formed by the heights.

At the beginning of the 18th century the parabolic theory and Grandi's assumption were accepted as true by nearly all the writers on hydraulics, and these were maintained up to the end of the century, with varying modifications as some fact was discovered inconsistent with them; in fact, Grandi's immovable layer of water on the sides and bottom over which the rest flowed, was taught and accepted by our foremost hydraulicians up to quite recent times.

Many mathematicians and observers, during the early part of the 18th century, published results and observations, which, however, have now no influence on the subject. Up to 1775 it had been recognized that gravity acting upon the slope of the surface of the water produced the motion in a stream, and that the adhesion of the water to the sides and bottom, and the resistance of inequalities there, tended to diminish the velocity. It had also been recognized that the stroke or force of a stream of water was proportional to the velocity and to the number of particles which strike in a given time, or, on the whole, as the square of the velocity. Chezy, a celebrated French engineer, in 1775 was the first to suggest that, in the case of a stream in uniform motion, the forces of acceleration must equal those of retardation. He adopts Grandi's assumption of a layer of immovable liquid particles lining the channel, and considers the accelerating forces to be the action of gravity, the height the water falls in the given length, and the area of the cross-section of the stream. For the retarding forces he put the length of the channel, the length of the wetted border or perimeter, and some function of the square of the velocity. The equation then is—

$$2ghA = fv^2lp \text{ ....}(2),$$

in which h is the height the stream falls in the length l, A the area of the cross-section, p its wetted perimeter, and f a function of the square of the velocity to be determined by experiment. Putting

$$\frac{A}{p} = r, \text{ the hydraulic mean depth, or mean radius,}$$

$$\frac{h}{l} = s, \text{ the sine of the inclination,}$$

we have $$\frac{2g}{f} rs = v^2 \text{ ....}(3),$$

and putting $$\sqrt{\frac{2g}{f}} = c,$$

i.e., a co-efficient, which varies with certain circumstances, hereafter described, we get

$$v = c\sqrt{rs} \quad \text{..............................} (4),$$

which is now generally called the Chezy formula, and *is the general formula for all cases.*

Dubuat, who has been called "the creator of the positive science of running waters," published his great work in 1786. He accepted the erroneous theory of Grandi. He found, as had been previously shown by others, that the slope of the surface of the water alone causes motion, and found there was a close analogy between the flow of water in close pipes and that in open channels, and that more accurate observations could be made on pipes than on channels. He adopted Chezy's formula and the reasoning which led up to it, and found that *no single value of* c *gave correct results for channels varying in velocity, or varying in the area of their section.* This was a most important point. In framing his formula he proceeded by purely empirical methods, and it is important to note the experiments which he used. These were 125 in all: 89 upon pipes, and 36 upon open channels. Those upon pipes consisted of—

7 by Couplet (1732) upon iron pipes, six being on a 5-inch pipe and one on an 18-inch pipe.
26 by Bossut (1771) upon new tinned iron pipes 1, $1\frac{1}{3}$, and 2 inches diameter.
38 by himself upon new tinned iron pipes from $\frac{1}{11}$ to $\frac{1}{4}$ inch diameter.
18 also by himself on the same kind of pipe 1 inch diameter.
—
89

Those upon open channels were :—

26 by himself upon small wooden troughs.
6 upon the Canal du Jard ; and
4 upon the River de Hayne.
—
36

It will be observed how minute the most of these channels were.

Notwithstanding the imperfect data at his command, Dubuat was able to show, first, that the resistance decreased as the velocity increased ; and second, that it decreased as the hydraulic mean depth r increased; and he introduced terms into his equation to allow for these.

He adopted Chezy's formula—

$$v = c\sqrt{rs}.$$

Dubuat's formula is

$$v = 88{\cdot}5\frac{\sqrt{r} - 0{\cdot}03}{\sqrt{\frac{1}{s}} - \text{hyp. log.}\left(\frac{1}{s} + 1{\cdot}6\right)} - 0{\cdot}089\left(\sqrt{r} - 0{\cdot}03\right) \ldots (5).$$

This formula, though tedious to work, was accepted and used by engineers in Britain for more than 60 years as the formula which gave the most accurate results.

Venturi, in 1798, says:—"The eddies which are incessantly formed in a river by the dilatations in the bed, the cavities of the bottom, the inequalities of the banks, the windings of its course, and the currents which cross each other, retard the flow. Every eddy destroys a part of the moving force of the current of a river."

The 19th century opens with experiments by Coulomb upon the friction between fluids and solids. Hitherto it had been assumed that the resistance was proportional to v^2, but Coulomb showed (1) that for velocities of less than 6 inches per second the frictional resistances were sensibly proportional to the velocities; (2), for velocities above 6 inches per second the resistances were more nearly proportional to the square of the velocities; and (3), generally, that the resistances could be expressed by a function of the velocity and a function of the square of the velocity, thus—

Total resistance $R = av + bv^2$, where a and b are co-efficients.

His experiments were made by means of metal discs, supported by torsion wires, and at the low velocities he used he did not find that the nature of the surfaces had any influence on the friction.

Coulomb did not apply his discovery to the flow of water, but it immediately attracted the theoretical instincts of the French mind, and for more than 50 years the theorem was adopted by all writers on hydraulics. We have, then,

$$rs = av + bv^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6).$$

Solving the quadratic, we have

$$v = \left(\frac{rs}{b} + \frac{a^2}{4b^2}\right)^{\frac{1}{2}} - \frac{a}{2b} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7).$$

It was assumed that the co-efficients a and b were equal in value. In 1804 Prony published his great work upon *The Theory of the Flow of Water.* He accepted Grandi's erroneous theory of the fluid lining of pipes, and adopted Coulomb's expression for the resistances. He found that the value of the constants a and b should not be equal. He made no experiments himself, and simply used those given by Dubuat, which we have already seen to be somewhat defective.

The equations he obtained were for pipes—

$$v=(9{,}425rs+0{\cdot}006663)^{\frac{1}{2}}-0{\cdot}081625 \quad \ldots\ldots\ldots\ldots(8),$$

or

$$v=97\sqrt{rs}-0{\cdot}08 \text{ nearly} \quad \ldots\ldots\ldots\ldots\ldots\ldots(9);$$

and for open channels—

$$v=(10{,}607{\cdot}5rs+0{\cdot}055577)^{\frac{1}{2}}-0{\cdot}23575 \quad \ldots\ldots\ldots(10),$$

or

$$v=103\sqrt{rs}-0{\cdot}236 \text{ nearly} \ldots\ldots\ldots\ldots\ldots\ldots(11).$$

All the writers, for 50 years after Prony, adopted Coulomb's formula and Prony's values of the co-efficients, with only slight variations following upon a few additional observations, but nearly all upon large channels.

Eytelwein, in 1814–15, proposed slightly different values for the co-efficients. His values give for pipes—

$$v=108{\cdot}2\sqrt{rs}-0{\cdot}13 \text{ nearly} \ldots\ldots\ldots\ldots\ldots\ldots(12),$$

and for open channels—

$$v=94{\cdot}7\sqrt{rs}-0{\cdot}11 \text{ nearly} \quad \ldots\ldots\ldots\ldots\ldots\ldots(13).$$

D'Aubuisson, in 1834, adopted Eytelwein's values for open channels, but for pipes he proposed values which give

$$v=98\sqrt{rs}-0{\cdot}1 \text{ nearly} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(14);$$

but when the velocity in the pipe exceeds 2 feet per second,

$$v=95{\cdot}63\sqrt{rs} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(15).$$

Weisbach, in 1846, made a slight alteration upon the co-efficients for open channels, which gives

$$v = 93{\cdot}2\sqrt{rs} - 0{\cdot}015 \text{ nearly} \ldots\ldots\ldots\ldots\ldots\ldots (16).$$

For pipes he used the following:—

$$v = \frac{1}{\left(a + \frac{b}{\sqrt{v}}\right)}^{\frac{1}{2}} \sqrt{rs}.$$

In all these formulæ based on Coulomb's theory the values of the co-efficients vary simply with the velocity, and are independent of the size, shape, inclination, and condition of the channel.

It will be observed that all the values of the co-efficient c given above have a range of only a little over 10 per cent. *Dubuat's discovery of the influence of the hydraulic mean depth had been ignored.*

In England, in 1802, Dr. Thomas Young presented to the Royal Institution a summary of a work published by Eytelwein in 1801, which was in great part founded upon Dubuat's experiments. He proposed the formula for pipes

$$v = 100\sqrt{rs} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (17),$$

and for rivers

$$v = 93{\cdot}42\sqrt{rs} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (18).$$

Sir John Leslie also, in 1823, proposed for both pipes and rivers

$$v = 100\sqrt{rs} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (19).$$

or

$$Q = 2356 d^{\frac{5}{2}}\sqrt{s}.$$

Beardmore published the first edition of his *Hydraulic Tables* in 1850, and they are still much used. For pipes he adopted Young's and Sir John Leslie's value of c, and tabulated for a large number of diameters the part of the expression

$$2356\, d^{\frac{5}{2}}.$$

These tabular numbers, multiplied by the square root of the sines of the inclination, give the discharge per minute. For drains and rivers, he adopts Eytelwein's simple formula with a slight alteration. He puts

$$v = 94{\cdot}2 \sqrt{rs} \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (20).$$

Neville, in 1853, considers Dubuat's as the most reliable formula, and gives tables for calculating velocities.

His formula

$$v = 140 \sqrt{rs} - 11 \sqrt[3]{rs} \ldots\ldots\ldots\ldots (21),$$

is still used, and his tables are given in Hurst's *Hand Book* and Molesworth's *Pocket Book.*

Downing, in his *Practical Hydraulics*, published in 1855, adopts Young's and Sir John Leslie's value of c for both pipes and open channels, viz. :—

$$v = 100 \sqrt{rs}.$$

A discussion in the Institution of Civil Engineers, in February, 1855, shows that up to that time English hydraulic engineers held to Grandi's theory, and the principle was maintained that the resistance to the flow of water was, within certain narrow limits, independent of the surface of the material over which it flowed, and that all channels, whether constructed with an earthenware, brick, metallic, or vitrified surface, offered the same resistance to fluid motion.

In the middle of the present century, then, the position of the question was this. On the Continent, Coulomb's discovery, and the value of the constants attached to it by Prony, or some slight modifications of them, ruled supreme; while in England Grandi's theory was stoutly maintained to be true, and Dubuat's formula, or the Chezy form of it, with a constant value of c varying little from 100, were used for all the important works that were executed up to that time, and, in fact, for those constructed for several years afterwards. But several engineers had observed that the discharge of their pipes and channels often fell far short of that assigned to them by formula. D'Aubisson, in 1829, in a letter to M. Arago, says from his experiments on the water pipes of Toulouse, which had been some years in use, that the loss of head was sometimes more than double that indicated by Prony's formula; and he had been brought to use a formula which supposes the resistance to be proportional to the simple square of the velocity, and that for practical results the head ought to be doubled.

The value of c he used was

$$v = 95{\cdot}66\sqrt{rs} \quad \text{(22)},$$

which for pipes long in use he proposed to reduce to

$$v = 67{\cdot}64\sqrt{rs} \quad \text{(23)}.$$

Mr. David Stevenson, about 1853, finding, from careful measurements of the flow of some rivers, the formula by Dubuat, Sir John Leslie, and others, then accepted as the most accurate, gave results considerably in excess of the observations, was led to propose for large rivers the following :—

$$v = 96{\cdot}12\sqrt{rs} \quad \text{(24)},$$

and for small streams, under 2,000 cubic feet per minute,

$$v = 69{\cdot}42\sqrt{rs} \quad \text{(25)}.$$

being a deduction of about 30 per cent.

Towards the middle of the 19th century, then, the subject had become involved in uncertainty and confusion, although it had engaged the attention of many great scientists. Calculations based upon elaborate formulæ differed so largely from actual observations that distrust of the formulæ had been created, a distrust which, even up to present times, is not unknown.

To a French engineer, M. Henri Darcy, is due the honour of having at last discovered what we now believe to be the true principles on which the flow of water must be calculated, and his methods afford to us another illustration of the truth that great scientific results are achieved not so much by the application of rigid theory as by the patient investigation of a long series of practical experiments, carried out under a variety of circumstances, and then utilized by mathematical science.

M. Darcy, in 1850, commenced experiments upon the discharge of pipes in the vicinity of Paris; they were completed in 1851, presented to the French Academy in 1854, and published in 1857. He used pipes of all sizes up to 11½ inches, and one 19½ inches diameter, of glass, lead, wrought iron, new cast iron, coated and uncoated, and cast-iron pipes that had been some years in use. His observations were 198 in number, were carried out with great accuracy, and on a scale which gives them great practical utility.

He found, first, that for velocities of about 4 inches per second and less, the resistance to the flow was sensibly proportional to the simple velocity, or

$$rs = av \quad \text{............................} (26).$$

In this case a is a co-efficient varying with the nature of the material of the pipe and its condition, as ascertained by experiment. For higher velocities, and especially in the case of pipes that had been in use a considerable time, the resistance was found by M. Darcy to be proportional to the square of the velocity, or

$$rs = b_1 v^2 \quad \text{............................} (27),$$

which is the formula of Chezy.

Second, that, as Dubuat had found, the resistance decreased as the diameter increased, and that the numerical value of b_1 could be represented by the equation

$$b_1 = a + \frac{b}{r} \quad \text{............................} (28).$$

b is also a co-efficient determined by experiment, the latter term varying inversely as the hydraulic mean depth. From this we have

$$v = \left(\frac{1}{a + \frac{b}{r}} \right)^{\frac{1}{2}} \sqrt{rs} \quad \text{....................} (29).$$

For new cast-iron pipes he found the following values of a and b in English feet:—

$$a = 0{\cdot}00007726,$$
$$b = 0{\cdot}0000016175.$$

Dr. Rankine, in 1869, put these co-efficients into the following very simple form, without sensibly altering their value:—

$$v = \left\{ \frac{2g}{0{\cdot}005\left(1 + \frac{1}{12d}\right)} \right\}^{\frac{1}{2}} \sqrt{rs} \quad \text{............} (30),$$

where d is the diameter of the pipe. In this equation the values of c, *i.e.*, the amount included within the brackets, range from 98 for a 3-inch pipe to 112 for a 48-inch pipe. On this equation the results given in tabular form later on in this chapter are based.

But more important than these was the discovery, with which Darcy's name must be ever associated, that, contrary to the received opinion, the nature of the surface of the pipe *had* a controlling influence upon its discharge, thus finally disposing of Grandi's assertion. Taking three kinds of pipes experimented upon, viz. :—(1), iron, coated with bitumen; (2), new cast-iron pipes; and (3) cast-iron pipes covered with deposit, he found the co-efficients of resistance b_1 in equation 29, to vary nearly in the proportion of 0·74 : 1 : 2. The discharges being inversely as the square roots will be proportional to 1·16 : 1 : 0·707. So that for coated pipes 16 per cent. should be added, and for pipes long in use 30 per cent. should be deducted from the discharges obtained by equation 31. The values of c under this deduction range from 69 for a 3-inch pipe to 80 for very large pipes.

He points out that it is useless to consider the co-efficients of pipes coated with bitumen, because in a time more or less remote they become covered with deposit, and it is this last result that ought always to be kept in view. In practice this is equivalent to taking one-half the height only as effective, and the probable thickness of a layer of deposit should be allowed for in addition. This deposit may vary from $\frac{1}{2}$ to 1 inch in thickness, depending upon the amount of solid matter in the water.

The result of these experiments led Darcy to believe that similar results would be got in the case of open channels, and in 1856, having obtained the support of the Minister of Public Works, he commenced his experiments. The experimental channel was of wood, 2 mètres wide, 1 mètre deep, and 600 mètres long, and by means of false bottoms and sides he varied the slope and profile of the channel, and lined the bed and banks with a variety of materials. Darcy died in the early part of 1858, but the observations were continued by M. Bazin, his assistant, and concluded in January, 1862, after having been seven years in hand. The memoir was presented to the Academy in 1863, and the whole was published in 1865.

The observations were made with great care, and were supplemented by observations upon other canals and water channels; in all, Darcy and Bazin used 500 observed results. They found, first, that the resistance varied, not with the velocities, but with the value of the mean radius, diminishing as the section increased, and, therefore, that the binomial form of equation adopted by Prony and others can only lead in practice to very grave errors, and ought to be completely abandoned, and also that the resistances were best expressed by the formula used by M. Darcy for pipes, viz. :—

$$rs = \left(a + \frac{b}{r}\right) v^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (31).$$

Second, that the resistances varied infinitely with the condition of the wetted perimeter, and that it was not possible to get a single formula applicable to every case.

As the values of the co-efficients a and b in equation 29 depend entirely upon the nature of the surface of the channel, which is almost infinitely variable, and escapes all theoretical estimation, Bazin formed his experiments into four classes or categories, which, of course, do not include every degree of roughness of the wetted perimeter, but which correspond to some of the cases met with in ordinary practice. These are :—

1. Channel very smooth, pure cement, wood planed with care.
2. Smooth channel, cut stone, cement with sand, brickwork, planks, etc.
3. Less smooth channels, rubble masonry.
4. Channels in earth.

For the sake of convenience he wrote his formula thus :—

$$rs = a\left(1 + \frac{b}{r}\right) v^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (32),$$

so that we have in the Chezy formula

$$c = \left\{ \frac{1}{a\left(1 + \frac{b}{r}\right)} \right\}^{\frac{1}{2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (33).$$

It follows, from this expression, that the value of c in each of the above classes remains constant for all channels, with the same mean radius, whatever the inclination and consequently the velocity may be. With r, or mean radius, equal to 2, the following are the values of c in the four classes :—

1 class, $c = 144{\cdot}4$.
2 ,, $c = 124{\cdot}5$.
3 ,, $c = 98{\cdot}5$.
4 ,, $c = 62{\cdot}0$.

Darcy and Bazin go on to show how it was that the condition of the perimeter and the influence of the value of r had escaped recognition by the early observers. They show that Dubuat's 36 experiments, Prony's 31 experiments, and the large additional number given by Eytelwein, divide themselves into two very distinct categories, and that these are practically two extreme cases. The planks composing the small experimental channels offered much less resistance to the flow than the earth of the larger channels, while the value of r in the latter was much larger than in the case of the troughs. These two causes of variation acting, the one to diminish the resistance, and the other to augment it, tended to compensate each other in such a way that the value of the co-efficient c remains nearly the same.

We now come to the latest development of the theory of the motion of water in channels. This is due to M.M. Ganguillet and Kutter, of Berne, who published their researches in 1869 and 1870, and these were translated into English by Louis D'A. Jackson in 1876. These gentlemen brought to bear upon the enquiry not only all previously recorded experiments, but a number of observations by themselves on the flow in some of the regulated torrents of Switzerland, which are encumbered by detritus, and have great inclinations, as well as a large number of experiments by other observers.

They found that the old formula of Chezy (4) could be adapted to all the observations, and they examined the variations of c for a great variety of cases. Darcy and Bazin had proved that its value depended upon—

1. The value of the mean radius.

2. The roughness of the perimeter, and Ganguillet and Kutter now found that it also depended

3. On the slope of the stream, which, from the limited range of Darcy and Bazin experiments, they had thought to be unimportant.

They first proposed to extend the four categories of Darcy and

Bazin, as they were limited in application, and calculated co-efficients for a series of 12 categories, but observing that in Bazin's formula when r is infinite c becomes 148, 131, 117 and 108·3 in their respective categories, a result which they considered inadmissible in the case of large rivers, they concluded that in this respect, as well as regards the influence of the inclination, Darcy and Bazin's formula must be considered defective.

As regards the influence of the *roughness* of the channel, they found—

1. For small channels differences of roughness have a great influence on the discharge.
2. For very large channels differences of roughness have very little influence.
3. For indefinitely large channels the influence of different degrees of roughness must be assumed to vanish.

Further consideration showed the probability of obtaining a general formula, which could be adapted to practical application, and which would include the influence of the dimensions of the channel, the slope of the stream, and one variable co-efficient representing the roughness of the perimeter. Such a formula could not, of course, be a simple one. In carrying on their enquiry they proceeded in a purely empirical manner, and after much investigation they found that the following value of c, in the Chezy formula, would satisfy all the conditions and give results sufficiently accurate for practical use :—

$$c = \frac{a + \frac{l}{n} + \frac{m}{s}}{1 + \left(a + \frac{m}{s}\right)\frac{n}{\sqrt{r}}} \text{......................} (34),$$

in which a, l, and m are constants, and n the variable co-efficient depending upon the roughness of the surface. The values found for a, l, and m were 41·6, 1·811, and 0·00281 respectively, and the formula becomes

$$v = \left\{ \frac{41{\cdot}6 + \frac{1{\cdot}811}{n} + \frac{0{\cdot}00281}{s}}{1 + \left(41{\cdot}6 + \frac{0{\cdot}00281}{s}\right)\frac{n}{\sqrt{r}}} \right\} \sqrt{rs} \text{ ....} (35).$$

It will be seen from the foregoing that any formula which, for all cases of slope and nature of the surface, takes the value of c as constant, is unreliable.

This conclusion was further tested by Captain (now Colonel) Allan Cunningham, R.E., in another long series of patient and exhaustive experiments* made on the Ganges Canal, near Roorkee, in 1874–83. His experiments, having been made on a large irrigation canal, are more generally applicable to that class of engineering than to the limited quantities of water, comparatively speaking, required for a water supply.† Some of his conclusions are of great importance on practical points, such as the effect of silt and the amount of evaporation. Observations on the velocity at various depths and at various positions of the surface, and under various conditions of the wind, were also most carefully made, but the broad fact of the greatest importance for our present purpose is that he proved that the only two formulæ of sufficient value to be worth considering are those of Darcy and Kutter, "that most of such hydraulic results as were previously accepted by only the few have now been so verified on a large scale as to command their acceptation by the many."‡

The researches of M. Darcy having been carried out on pipes, while those of M. Kutter and Captain Cunningham were on open channels, we may fairly conclude that (a) for pipes M. Darcy's results are sufficiently accurate, but that (b) for masonry conduits or earthen channels Kutter's formula should be employed.

On that assumption we proceed to investigate the

Motion of Water in Pipes Running Full.

If a vessel as ABCD, *Fig.* 74, be filled with water up to the line EF, we know that the pressure at any points G and H at equal depths EG and FH will be the same. If we insert two pipes of the same bore at G and H, the amount of water that will flow through the orifices at G and H will be equal, and will be unaffected by the opening of any other taps in the vessel, provided the level EF remains constant.

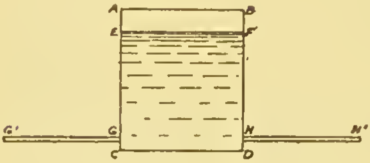

Fig. 74.

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* See *Minutes of Proceedings, Institution of Civil Engineers*, Vol. LXXI., 1.

† For this reason also I have not touched upon the experiments made in 1861 by Messrs Humphreys and Abbott on the Mississippi.

‡ *Vide* Jackson's *Hydraulic Manual*, p. 203.

If the two pipes GG′ and HH′ are of the same length, the amount flowing out will be the same. But if, as in *Fig.* 75, GG is much longer than HH′, the amount which flows out at G′ will be less than that flowing out at H′, because the friction of the pipe will have a retarding effect. If, therefore, we wish to get the same amount of water from G′ that we did formerly, we must by some means raise the level of the surface EF to E′F′. The difference EE′ or FF′ is *the head* required to overcome the friction in the difference in length between HH′ and GG′.

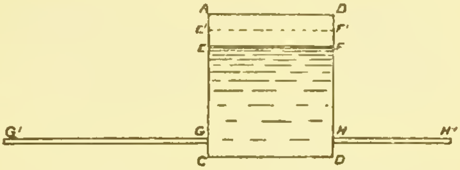

Fig. 75.

To take another illustration.

A reservoir with water level AB (*Fig.* 76) is required to supply a given quantity of water to a tank at a given distance through a pipe, and it is required to know at what height the level of the water in the tank must be. If there was no friction in the sides of the pipe, nor any other obstructing cause, the level at CD might be the same as AB. But owing to the friction and certain other minor obstacles, the water level at CD must be lower than AB, and the difference in level between the two, BE, is the *frictional head.*

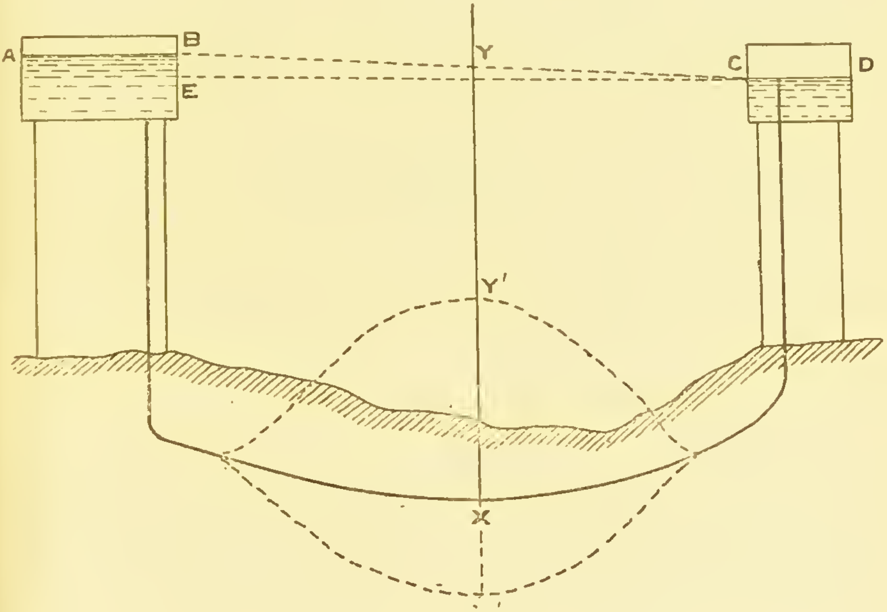

Fig. 76.

If a line be drawn from the surface AB to the surface CD, this line would be called the *hydraulic gradient*, sometimes called *hydraulic mean gradient* or *virtual slope.* Assuming that the two tanks are connected by a main EXF, if a vertical pipe XX′ were inserted at any point X on the connecting main, the water would rise as high as the line of the hydraulic gradient at Y′. It would make no difference in the height of Y if X were above or below its indicated position, say at Y_1 or X_1, *as long as it did not rise above the hydraulic gradient.*

In masonry channels or any other form of aqueduct where the water is not flowing under pressure, it is evident that the longitudinal section of the channel must be that of the hydraulic gradient.

In pipes under pressure, the line may rise above the hydraulic gradient and act as a syphon, but it is likely to give trouble.

In the case of a pipe leading from a vessel, and furnished with a tap at the end, the hydraulic gradient is drawn from the surface of the water to the point of delivery of the tap. Thus, in *Fig.* 77, the hydraulic gradient of the pipe OT′ is ET′, and of the pipe HH′ FH′. When the tap is running at T the head at X will be XX′, and if there were a series of pipes along OT the level of the water in them when the tap was opened would give ocular proof of the line of the hydraulic gradient.

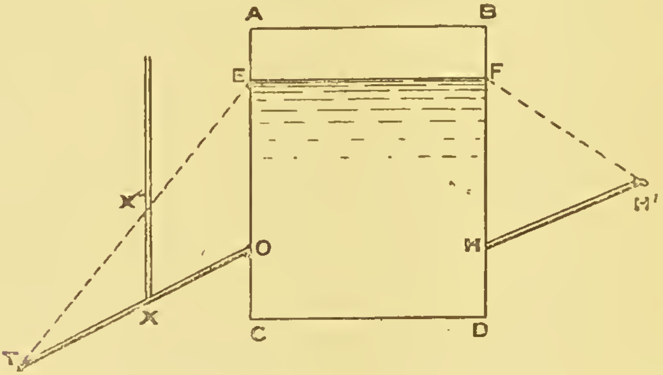

Fig. 77.

Let us now suppose there is a main pipe (a *plan* of which pipe is shown in *Fig.* 78) ABCDE flowing in the direction of the arrows and supplying taps at F, F′, D′, C′, B′, and let it first be assumed that the taps and main are all on the same level, and that they are each to supply the same quantity, Q. Beginning at the point E, it is evident that if EF′ be longer than EF the *frictional head* required at E will need to be such as will supply Q cubic feet per second at F′.

If the head is enough to supply this at F′, it will also be sufficient to supply the same quantity and more at F.

We now come back to D. The total *quantity* to be supplied will be 2Q, that is to say, Q at F and Q at F′, the *length* through which that quantity has to be supplied is DE, and hence we must find what *frictional head* is required at D to force the quantity 2Q through the length DE.

What about the length DD′? If the head at D is sufficient to supply 2Q through DE it will be more than sufficient to supply Q through the shorter length DD′.

Next, going back to C, we have to supply 3Q through the length CD, and must find the frictional head required at C to force that amount through the length CD.

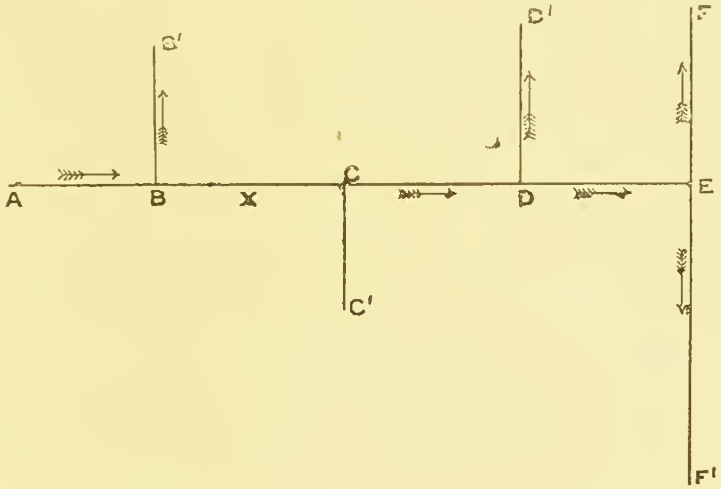

Fig. 78.

Thus working back we arrive at the necessary head at A to supply the whole system.

The hydraulic gradient along the pipe ABCDEF may now be drawn to any scale, as in *Fig.* 79.

Here E*e* represents the calculated head at E, *ed* is drawn parallel meeting the vertical through D at *d*. From *d* the line *dd′* is drawn equal to the calculated head at D, and so on. The line joining *a′b′c′d′e*F is the hydraulic gradient.

The head at any point on the line, say *x*, between B and C is found by drawing a line from *x* on the section to the hydraulic gradient line, at *x′*.

In this example we have assumed, for the sake of simplicity, that the quantities supplied are the same, that the pipes are all of the same size, and that the whole system is on the same level. Such conditions would seldom obtain in practice. The *quantities* required would probably vary. In barracks the assumption is that $\frac{1}{4}$ of the total quantity required in the 24 hours at any point should be delivered in one hour. This quantity, which we can, therefore, easily express in cubic feet per second, varies with the nature of the building to be supplied, *e.g.*, officers' mess, men's ablution room, etc. The *diameters of the pipes* would vary. The larger the pipes the less the head required to supply the given amount, and, therefore, the less the height of the service reservoir.

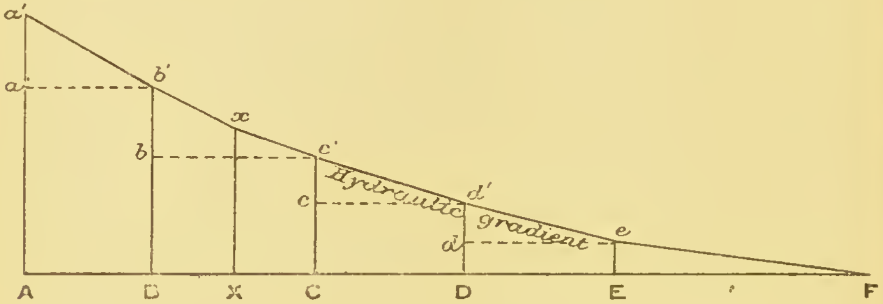

Fig. 79.

Taking a pipe system of exactly the same plan as formerly, but representing the supply to points on different levels, such as the cisterns of houses, the whole being situated on sloping ground, as shown by the contour in *Fig.* 80, we have to go through exactly the

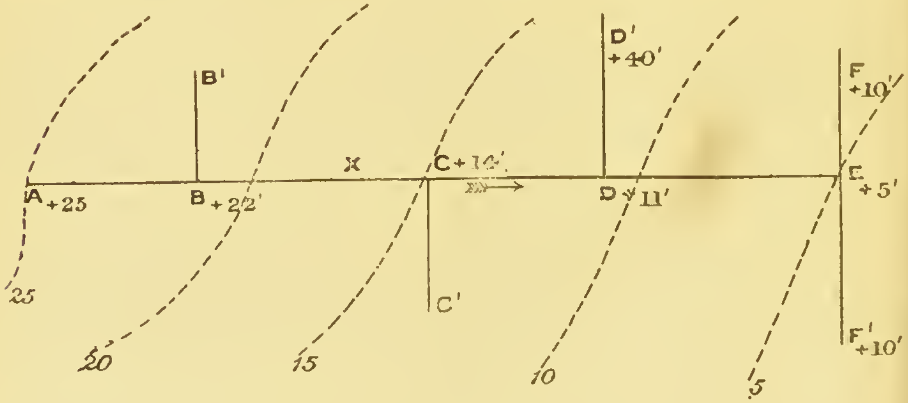

Fig. 80.

same process as before, but it will not be possible in every case by mere inspection to tell which of two given branches will require the greater head. For instance, at the point D it may require a greater head to deliver a given quantity at D′ 40 feet above ground than at F and F′ 10 feet above ground. Each branch will be considered on its own merits, and it will be necessary to make the calculation for each to determine the maximum head required.

In taking the length of the pipe, it will now be necessary not merely to measure it from the plan, but to include the vertical or rising portion as well.

As regards the total head required at A, it will evidently now be at least as much as the level of the highest tap plus the frictional head required to drive the water through AB for the supply of the whole system. The fact of A being on ground rising 20 feet above D will tend to economy in the height of the tank or reservoir at A. This will be evident from *Fig.* 81, which shows the hydraulic gradient.

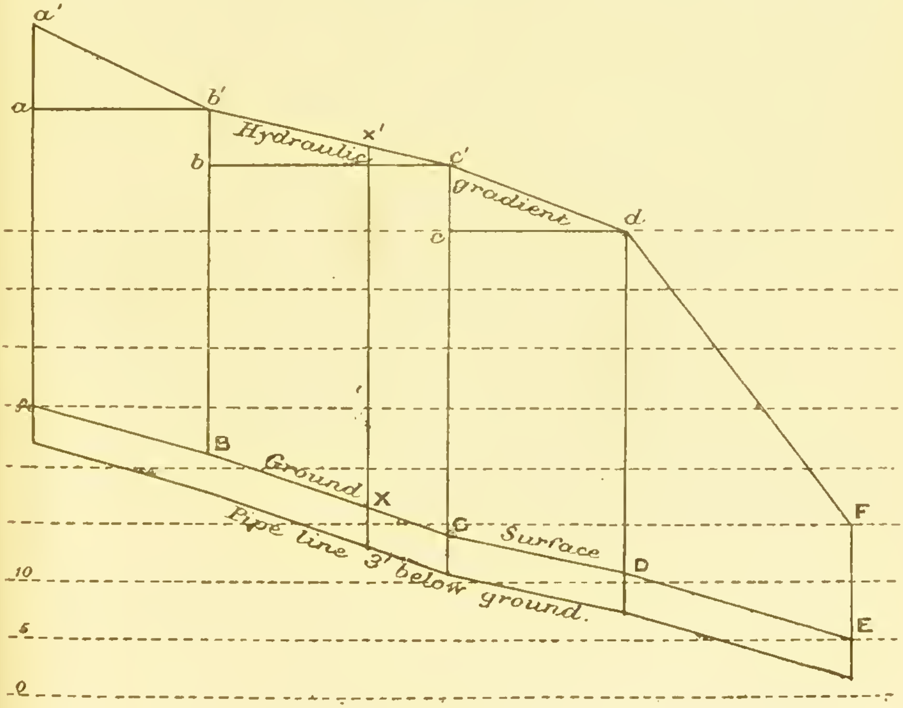

Fig. 81.

First draw the section of the ground along ABCDE, showing the contours, at any vertical scale. Then, at the proper depth, say 3 feet below surface, draw the line of the pipe. At the same scale set off D*d* above ground, showing the level of the highest tap or cistern in the system. Draw *dc* horizontal, meeting the vertical C*c* at *c*. Calculate as before the frictional heads *cc*′, *bb*′, and *aa*′, laying them off successively as before. Then *a*′*b*′*c*′*d*F will be the hydraulic gradient, EF being the height above ground of the tap at F.

The head at any point X in the pipe is found by drawing XX′ and measuring it to the scale of vertical heights.

A*a*′ will be the necessary height of the tower or reservoir.

A percentage, however, must be added on to account for minor losses of head, treated in all purely hydraulic calculations, *e.g.*, loss due to orifice of entry, gurglitation, inertia of water, and bends in the pipe. With the exception of the last, these are practically seldom of much moment, but if a small percentage is added in most ordinary cases to the calculated head it will suffice to meet requirements.

Now, in order to calculate the frictional head, having given the diameter of the pipe, the length and the quantity to be discharged, it is only necessary to apply the following formula*:—

$$h = \frac{Q^2 l}{K} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (36).$$

When h = frictional head in feet.

Q = quantity discharged in cubic feet per second.

l = length of the pipe in feet.

K = a co-efficient varying with the diameter of the pipe and its condition, for obviously there will be a good deal of difference between a new pipe, smooth and clean, and an old incrusted pipe full of rough matter.

The values of ζ, k, and of K, based on M. Darcy's experiments, are given in Table A at the end of this chapter.*

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* The proof of the above formula is as follows :—

$Q = Av$ where A is the area of the cross-section (*i.e.*, $\frac{\pi d^2}{4}$ for a circle or pipe with diameter $= d$), and v = velocity in feet per second $= \sqrt{\frac{2g}{\zeta}}\,\sqrt{rs}$ where ζ = co-efficient of friction $= \cdot005\left(1 + \frac{1}{12d}\right)$ for smooth, and $\cdot010\left(1 + \frac{1}{12d}\right)$ for incrusted pipes [for values see Table A]; r = hydraulic mean depth, *i.e.*, area ÷ wetted perimeter, and, therefore, in a pipe of circular cross-section, flowing full, $r = \frac{\pi d^2}{4} \div \pi d = \frac{d}{4}$; and s = sine of inclination $= \frac{h}{l}$.

In tables usually given of discharges the quantities are generally given in gallons per minute. To save calculations, a few examples are give in Table B, at the end of this chapter, and any other cases for equal diameters of pipe may be worked out by simple proportion. Thus let it be noted from tables that a 5-inch smooth, new pipe 100 feet long, with a discharge of 1·44 cubic feet per second, or 540 gallons per minute, of soft water, requires 10 feet. head. Let it be required to discharge 300 gallons per minute of the same quality of water, through 300 feet of 5-inch equally smooth pipe, then to find head h' we call

$$Q=540,\quad l=100,\quad h=10$$
$$Q'=300,\quad l'=300,\quad h' \text{ is required.}$$

Then first find what head h'' would be required to discharge 300 gallons through the same length l, *i.e.*, 100 feet.

$$h''=\frac{Q'^2}{Q^2}\times h=3{\cdot}13.$$

Then if a head 3·13 is required for 100 feet, the head required for the same amount (300 gallons)

$$=\frac{l'}{l}\times h''=\tfrac{300}{100}\times 3{\cdot}13=9{\cdot}39 \text{ feet,}$$

or, in one quotation,

$$h'=\frac{Q'^2 l'}{Q^2 l}\times h.$$

Calculation of Open Channels.

Darcy's formula is not applicable to open channels. Kutter's is cumbersome to use, but fortunately there are many hydraulic tables

Writing $\sqrt{\frac{2g}{\zeta}}=k$, we have

$$Q=\frac{\pi}{4}\times d^2\times\frac{k}{2}\sqrt{d\frac{h}{l}};$$

$\therefore$ $$Q^2=\frac{\pi^2 d^5\times k^2}{64}\times\frac{h}{l}=\frac{Kh}{l},$$

i.e., $$K=\frac{\pi^2 d^5 k^2}{64}.$$

published in various works which give us the value of the troublesome co-efficient c for various cases.

Such a table, taken from Trautwine, is given at the end of this chapter (Table C), including all ordinary cases. The co-efficients n have the following value :—

Side and bottom lined with well planed timber $n = \cdot 009$
Neat cement, glazed pipes and very smooth pipes $n = \cdot 010$
Plaster, 1 sand to 3 cement, or smooth iron pipes $n = \cdot 011$
Unplaned timber or ordinary iron pipes ... $n = \cdot 012$
Ashlar or brickwork ... ... $n = \cdot 013$
Rubble ... ... $n = \cdot 017$

In the above the cross-section is supposed to be uniform. If there be irregularity of cross-section the value will be—

In very firm gravel ... ... $n = \cdot 020$
Canals and rivers of tolerably uniform cross-section, slope and direction free from stones and weeds ... ... $n = \cdot 025$
The same having stones and weeds occasionally $n = \cdot 030$
In bad order generally ... ... $n = \cdot 035$

To take an example as the simplest way of showing how such a problem may be practically solved, we may suppose that it is required to supply a cantonment with a population of 50,000 at 40 gallons per head per diem. Of the total 2,000,000 gallons 500,000, or $\frac{1}{4}$, may be required in one hour, or 24·6 cubic feet per second. We wish to know what size of conduit will be required, allowing a mean velocity of 3 feet per second, which, as stated in Chapter V., will be sufficient to prevent growth of weeds, and yet be sufficiently slow not to abrade the channel.

The cross-section of the channel will, therefore, be obtained from the formula $Q = Av$. In this case $Q = 24 \cdot 6$ and $v = 3$. Therefore $A = 8 \cdot 2$ square feet.

If we make the channel semi-circular, we find the diameter d very easily, for

$$\frac{\pi d^2}{8} = 8 \cdot 2 \text{ and } d = 4 \cdot 6 \text{ feet.}$$

Now the hydraulic mean depth, or r, for a semi-circle $= \frac{d}{4} = 1 \cdot 1$ foot; hence in the equation

$$v = c\sqrt{rs}$$

we know the values of v and of r, and we can, by trial and error, find c and s from tables. Assuming that the channel is made with smooth plastered sides, and that the slope is to be 1 in 5,000, we can calculate the velocity and compare it with that allowed by hypothesis. Thus, if $n = \cdot 011$ we find from tables that $c = 138$ for a H.M.D. of 1·1; hence

$$v = 138\sqrt{1 \cdot 1 \times \cdot 0002} = 2 \cdot 06,$$

which is not sufficient. It would be practically difficult to make the sides smoother, so we must either increase the slope or increase the cross-section. From the tables a slope of 1 in 2,500 will give, with the same data,

$$v = 140\sqrt{1 \cdot 1 \times \cdot 0004} = \text{very nearly } 3.$$

The required conduit may, therefore, be semi-circular in cross-section, with smooth plastered sides, about 4 feet 8 inches wide and 2 feet 4 inches deep, with a fall of 2·112 feet per mile.

It might be made of rougher materials, but in that case would need a greater slope to have the same velocity. Or it might be given with the same slope a different *form* of cross-section. This would have the effect of reducing the velocity, and, therefore, would necessitate a greater *area* of cross-section.

Let us, in this latter case, suppose a rectangular cross-section is given 4 feet 6 inches wide, 2 feet deep. The value of the hydraulic mean depth will then be

$$\frac{4' \; 6'' \times 2'}{4' \; 6'' + 2 + 2}, = 1 \cdot 05.$$

Then if the sides are plastered as before, $n = \cdot 011$ and c from table $= 139$.

$$v = 139\sqrt{1 \cdot 05 \times \cdot 0004} = 2 \cdot 85 \text{ feet};$$

$$\therefore \qquad Q = 2 \cdot 85 \times 9 = 25 \cdot 65 \text{ cubic feet per second.}$$

The actual quantity required is 24·6, so the section is slightly larger than necessary.

In this case it will be seen that, although the *area* of the cross-section has been increased from 8·2 to 9 square feet, yet the *form* of the cross-section has, by its being changed from a semi-circle to a rectangle, diminished the velocity, and, therefore, affected the discharge to a very appreciable extent.

It may be, however, for practical reasons, advisable to construct a conduit of a large size and of rough masonry rather than of the semi-circular cross-section and smooth sides, which are theoretically the best.

In the foregoing example we have assumed that $\frac{1}{4}$ of the total amount is required in one hour. This is the basis of calculation in small quantities in barracks, but it must be observed that this rule, when applied to a considerable quantity, is not borne out by experiment. The quantity required would be very much less. The rate of consumption in a town will be, as previously pointed out in Chapter III., at a maximum 1·5 times the mean hourly consumption, and hence it would be generally sufficient if, instead of supplying 500,000 gallons per hour in the case above given, we had allowed $\frac{2,000,000}{24} \times 1{\cdot}5 = 125,000$ gallons per hour, or 5·5 cubic feet per second.

HORSE-POWER OF PUMPING ENGINES.

The calculation of horse-power is a very simple matter. The height H to which the water is to be raised from the surface of the well or other source of supply to that of the overhead tank or service reservoir must first be ascertained. The frictional head H′ which would be required to overcome the friction in the pipe leading from the well to the service tank must then be calculated on the principles already established. Then the horse-power actually required, after allowing for the friction in the mechanism of the engines and pumping mechanism, is

$$\frac{w \times (H + H')}{33,000} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (37),$$

w being the weight in lbs. of the water lifted in one minute. The actual horse-power should be at least ·8 of the indicated horse-power as developed by the cylinders.

Professor Burton, in treating of this subject, says that small engines (such as those which would be most usually required in barracks, etc.), should be made capable of developing in the cylinders twice the power that will ever actually be used. He gives, further, an approximate rule, which may be very useful:—

For each 1,000 of population 1 I.H.P. is sufficient, "pumping into a reservoir against a head of 100 feet, making ample allowance for friction, and also for stand-by and pumping. If pumping into the main direct, it is necessary to provide $1\frac{1}{2}$ I.H.P. per 1,000 of population, the other figures remaining the same."

Let us suppose we have 50,000 population to be supplied through 1,000 feet of pipe at a height of 200 feet. According to the above rule, the I.H.P. would be 100 or 150, according as the pumping was into a reservoir or into the main.

Using a 12-inch pipe, with a value for frictional head of 916 for the co-efficient K in an old pipe, we should have in the equation $h=\frac{Q^2 l}{K}$, $l=1{,}000$, $K=916$, Q (as in former example) $=5{\cdot}5$. Hence $h=33{\cdot}5$, and as the height to be raised is 200, we have a total height 233, to which $5{\cdot}5 \times 60 \times 62{\cdot}4 = 20{,}592$lbs. of water have to be raised.

Thus
$$\text{I.H.P.} = \frac{20{,}592 \times 233}{33{,}000} = 145.$$

This corresponds with Professor Burton's rough rule, but that rule evidently is very approximate, as it ignores the length, diameter, and condition of the delivery pipe.

Considerations Affecting Fire Protection.

In connection with fire hydrants, it is generally necessary to know—(1). The maximum height to which the jet will rise under given circumstances of head. (2). The maximum distance to which the water will travel.

If a body be thrown vertically with a velocity v feet per second, the height in feet to which it will rise *in vacuo* is thus found—

$$h=\frac{v^2}{64{\cdot}4},$$

and if projected at an angle θ with the horizon, then the curve which it describes is found from the equation

$$y = x \tan\theta - 16{\cdot}1\,\frac{x^2}{v^2 \cos^2\theta}.$$

To find the range, $x = \text{R}$ feet, $y = 0$; then

$$\frac{\sin\theta}{\cos\theta} \times \frac{v^2 \cos^2\theta}{16 \cdot 1} = \text{R},$$

or

$$\text{R} = \frac{v^2}{16 \cdot 1} \sin\theta \cos\theta.$$

When $\theta = 45°$, $\sin\theta = \cos\theta = \frac{1}{\sqrt{2}}$;

$$\therefore \qquad \text{R} = \frac{v^2}{32 \cdot 2} \qquad \text{.........................(38).}$$

This gives the maximum range.

To find the greatest height attained during the flight, $x = \frac{\text{R}}{2}$.

Then, substituting, we get first

$$y = \frac{\text{R}}{2} \tan\theta - 16 \cdot 1 \frac{\text{R}^2}{4v^2 \cos^2\theta}.$$

But

$$\text{R} = \frac{v^2}{16 \cdot 1} \sin\theta \cos\theta;$$

hence

$$y = \frac{v^2}{32 \cdot 2} \sin^2\theta - \frac{v^2 \sin^2\theta}{16 \cdot 1 \times 4} = \frac{v^2 \sin^2\theta}{64 \cdot 4}.$$

If the jet be directed at 45°—

$$\sin\theta = \frac{1}{\sqrt{2}}, \; y = \frac{v^2}{128 \cdot 8} \qquad \text{.................... (39).}$$

As these do not take account of the resistance of the air, a slight diminution both of the length of the trajectory and the height of the culminating point must be allowed for.

A matter of much importance is the size of the orifice from which the jet issues. This will affect the extent to which air resistance will reduce the height and length of the trajectory. The reduction in the stream caused by the nozzle causes also a loss of head, but the effect of the nozzle is to reduce the area of water upon which the atmosphere can act; hence the smaller the nozzle the greater the height and trajectory, other things being equal. The following table, founded on experiment, gives factors varying the ratio of head at the nozzle (h) to diameter of nozzle (d):—

$\frac{h}{d}$.	300.	600.	1,000.	1,500.	1,800.	2,800.	3,500.
Factor J	·98	·95	·92	·89	·84	·77	·71

To take an example:—

The head of water available at a hydrant is 40 feet. Find the length and height of the maximum trajectory, assuming that the nozzle of the hose is ½ inch.

A well-shaped nozzle reduces the velocity to 0·97 × that due to head.

Now,
$$h = \frac{v^2}{2g};$$

$$\therefore \quad v = \sqrt{64{\cdot}4 \times 40} = 51 \text{ feet per second};$$

or, reducing it by the factor due to the nozzle—

$$v = 51 \times {\cdot}97 = 49 \text{ feet per second.}$$

The greatest length of the trajectory, or the radius of the circle covered by the hydrant, will be

$$R = \frac{v^2}{32{\cdot}2} = 74 \text{ feet},$$

and height H, at a distance of $\frac{74}{2} = 37$ feet, from equation (39),

$$H = \frac{v^2}{128{\cdot}8} = 18\tfrac{1}{2} \text{ feet.}$$

Close to the hydrant, say at a slope of 75°, the height would be

$$H = \frac{v^2 \sin^2 \theta}{64{\cdot}4} \sin 75^\circ = {\cdot}966 \sin^2 75^\circ = {\cdot}92;$$

$$\therefore \quad H = \frac{49 \times 49 \times {\cdot}92}{64{\cdot}4} = 34{\cdot}5 \text{ feet.}$$

Hence this jet might be taken to cover 1-storied buildings 37 feet off, and 2-storied buildings nearer. For higher buildings the force-pump of the fire-engine must be brought into play.

At Aldershot the discharge considered necessary for fire protection at each hydrant is 120 gallons a minute. If the whole of this could be forced through the nozzle of a $\frac{1}{2}$-inch hose, the issuing velocity would be nearly 260 feet per second, involving a head of about 1,100 feet. As such a large head would be impracticable for the mains, it is evident that what the engineer has to arrange for is such a head as will supply 120 gallons per minute through the *hydrants*. In event of fire, these will be connected with the tank of the fire-engine, and the water will thence be forced through the hose according to the power available.

As the diameter of the hydrant is 3 inches, the issuing velocity of 120 gallons per minute is 6·5 feet per second, which would only involve a head at the hydrant of ·66 feet, so small an amount that practically there would be no difficulty in arranging for it under any circumstances.

As regards the distance apart of the hydrants, the theoretical maximum range and height of trajectory of a jet issuing with a velocity of 260 feet per second would be 2,000 and 500 feet.. But this would be impossible with the conditions of air resistance, frictional resistance of hose, and resistance of working parts of the engine. Practically, hydrants placed at 80 to 100 yards apart, capable of supplying 120 gallons a minute, will meet all requirements, and a well-drilled fire brigade, with an ordinary manual engine, will be able to direct streams of water on any barrack block within 100 yards of the hydrant. The radius of protected circle may thus be taken at 100 yards.

INFLUENCE OF BENDS ON PIPES.

At every bend in the pipe there is a loss of head, expressed in the following formula :—

$$H = bAv^2 \ldots\ldots\ldots\ldots\ldots\ldots (40),$$

where A is the number of degrees of direction, v = velocity in feet per second, and b is a co-efficient depending on the ratio $\frac{R}{d}$, *i.e.*, radius of bend divided by diameter of pipe. Table D gives the loss of head due to bends for a velocity of 1 foot per second. For other velocities, multiply by the square of the velocity.

TABLE A.

Diameter of Pipe.	ζ		k		K	
	Old Pipes.	New Pipes.	Old Pipes.	New Pipes.	Old Pipes.	New Pipes.
Inch.						
$\frac{1}{2}=\frac{1}{24}$	·030	·015	46	65	·000041	·000082
$\frac{5}{8}=\frac{5}{96}$	·026	·013	49	70	·000145	·000290
$\frac{3}{4}=\frac{1}{16}$	·02333	·01166	53	74	·000402	·000805
$\frac{7}{8}=\frac{7}{96}$	·02142	·01071	55	78	·00966	·001933
$1=\frac{1}{12}$	·02	·01	56	80	·001982	·003965
$1\frac{1}{8}=\frac{3}{32}$	·01888	·00944	58·4	82·7	·003819	·007638
$1\frac{1}{4}=\frac{5}{48}$	·018	·009	59·8	84·5	·006752	·013504
$1\frac{3}{8}=\frac{11}{96}$	·01727	·00863	61·0	86·5	011395	·022790
$1\frac{1}{2}=\frac{1}{8}$	·01666	·008	62	87·8	·018139	·036279
$1\frac{5}{8}=\frac{13}{96}$	·01615	·00807	63·2	89·4	·028062	·056124
$1\frac{3}{4}=\frac{7}{48}$	·01571	·00785	64	90·5	·041655	·083310
$1\frac{7}{8}=\frac{5}{32}$	·01533	·00766	64·8	91·7	·060383	·120767
$2=\frac{1}{6}$	·015	·0075	65 5	92·6	·085027	·170054
$2\frac{1}{4}=\frac{3}{16}$	·01444	·00722	66·8	94·5	·159573	·319146
$2\frac{1}{2}=\frac{5}{24}$	·014	007	67·8	95·9	·278305	·556610
$2\frac{3}{4}=\frac{11}{48}$	·01363	·00631	63·8	97·3	·461395	·922790
$3=\frac{1}{4}$	·01333	·00666	70·0	98	·72317	1·44634
$3\frac{1}{4}=\frac{13}{48}$	·01307	·00653	70·3	99·5	1·11236	2·22472
$3\frac{1}{2}=\frac{7}{24}$	·01285	·00642	70·9	100·3	1·63729	3·27458
$3\frac{3}{4}=\frac{5}{16}$	·01266	·00633	71·4	101·0	2·34413	4·68827
$4=\frac{1}{3}$	·0125	·00625	71·7	101·5	3·26900	6·53800
$4\frac{1}{2}=\frac{3}{8}$	·01222	·00611	72·6	102·7	6·03147	12·06294
$5=\frac{5}{12}$	·012	·006	73·2	103·6	10·39330	20·78660

TABLE A.—*Continued.*

Diameter of Pipe.	ζ		k		K	
	Old Pipes.	New Pipes.	Old Pipes.	New Pipes.	Old Pipes.	New Pipes.
$5\frac{1}{2} = \frac{11}{24}$	·01181	·00590	73·8	104 4	16·99800	33·99600
$6 = \frac{1}{2}$	·011666	·005833	74	105	26·56550	53·13100
$6\frac{1}{2} = \frac{13}{24}$	·01153	·00576	74·8	105 8	40·24590	80·40180
$7 = \frac{7}{12}$	·01142	·00571	75	106·2	58·73837	117·47675
$8 = \frac{2}{3}$	·01125	·00562	75·6	107	116·2522	232·5044
$9 = \frac{3}{4}$	·01111	·00555	76·1	107·7	212·2402	424·4804
$10 = \frac{5}{6}$	·011	·0055	76·5	108·2	362·7758	725·5517
$11 = \frac{11}{12}$	·0109	·00545	76·8	108·6	588·5816	1177·1632
$12 = 1$	$\cdot 0108\dot{3}$	$\cdot 00541\dot{6}$	77·0903	109·0221	916·4721	1832 9442
$13 = 1\frac{1}{12}$	·1077	·005385	77·3166	109·3422	1374·9153	2749·8306
$14 = 1\frac{1}{6}$	·0107143	·00535715	77·5173	109·626	2002·8659	4005·7318
$15 = 1\frac{1}{4}$	·0106666	·0053333	77·6902	109·871	2840·5506	5681·1012
$16 = 1\frac{1}{3}$	·010625	·0053125	77·8424	110·086	3937·7336	7875·4672
$17 = 1\frac{5}{12}$	·0105882	·00529422	77·9574	110·277	5350·5195	10701·0390
$18 = 1\frac{1}{2}$	·0105553	·00527644	78·0990	110 461	7144·4346	14288·8692
$19 = 1\frac{7}{12}$	·0105263	·00526316	78·2064	110·601	9385·7000	18771·4000
$20 = 1\frac{2}{3}$	·01050	·005250	78·3053	110 740	12160·0500	24320·1000
$21 = 1\frac{3}{4}$	·0104762	·0052381	78·3933	110·865	15554·9157	31109·8314
$22 = 1\frac{5}{6}$	·0104545	·0052272	78·4744	110·980	19669·0359	39338·0718
$23 = 1\frac{11}{12}$	·0104348	·0052174	78·5486	111·0845	24611·0340	49222·0680
$24 = 2$	·0104166	·0052083	78·6170	111·181	30500·1707	61000·3414
$25 = 2\frac{1}{12}$	·010400	·0052000	78·6800	111·270	37466·4000	74732·8000
$26 = 2\frac{1}{6}$	·0103846	·0051923	78·7382	111·353	45651·0921	91302·1842

TABLE A.—*Continued.*

Diameter of Pipes.	ζ		k		K	
	Old Pipes.	New Pipes.	Old Pipes.	New Pipes.	Old Pipes.	New Pipes.
27 $=2\frac{1}{4}$	·0103704	·0051859	78·7922	111·429	55207·6406	110415·2812
28 $=2\frac{1}{3}$	·0103571	·0051787	78·8426	111·500	66301·7880	132602·5761
29 $=2\frac{5}{12}$	·0103430	·00520731	78·8967	111·577	79126·4536	158252·9072
30 $=2\frac{1}{2}$	·0103333	·00516666	78·9333	111·629	93829·9586	187659·5173
31 $=2\frac{7}{12}$	·0103226	·0051613	78·9747	111·686	110660·7525	221321·5050
33 $=2\frac{2}{3}$	·0103125	·00515625	79·0130	111·741	129825·8267	259651·6535
33 $=2\frac{3}{4}$	·0103030	·00515151	79·0493	111·793	151558·3138	303116·6276
34 $=2\frac{5}{6}$	·0102941	·00514716	79·0836	111·841	176108·5824	352217·1648
5 $=2\frac{11}{12}$	·0102859	·00514285	79·1160	111·887	203742·2327	407484·4655
36 $=3$	·0102777	·00513889	79·1464	111·930	234740·8216	469481·6432

N.B.—$\zeta = \cdot005\left(1 + \frac{1}{12d}\right)$ for new pipes.

$= \cdot010\left(1 + \frac{1}{12d}\right)$ for old pipes.

$$k = \sqrt{\frac{2g}{\zeta}}.$$

$$K = \frac{\pi^2 d^5 k^2}{64}.$$

TABLE B.

Velocities and Discharges in Old and New Pipes, running full.

Size of Pipe.	$\frac{1}{10}$				$\frac{1}{20}$				$\frac{1}{50}$				$\frac{1}{100}$				$\frac{1}{500}$				$\frac{1}{1000}$				Size of Pipe.
	Old.		New.		Old.		New.		Old.		New.		Old		New.		Old.		New.		Old.		New.		
	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	
1″	2·58194	·01408	3·65142	·01991	1·82571	·00995	2·58194	·01408	1·15468	·00629	1·63296	·00890	·81648	·00445	1·15468	·00629	·36514	·00199	·51638	·00281	·25819	·00140	·36514	·00199	1″
1½″	3·55144	·04259	5·02249	·06023	2·51124	·03011	3·16522	·04259	1·58825	·01904	2·24613	·02693	1·12306	·01346	1·55824	·01904	·50224	·00602	·71028	·00851	·35514	·00425	·50224	·00602	1½″
2″	4·22659	·09221	5·97730	·13040	2·98866	·06520	4·22659	·09220	1·89019	·04123	2·67313	·05831	1·33657	·02951	1·89019	·04123	·59773	·01304	·84531	·01844	·42265	·00922	·59773	·01304	2″
2½″	4·89716	·16693	6·92098	·23592	3·46282	·11804	4·89388	·16682	2·19008	·07465	3·09516	·10550	1·54862	·05279	2·18861	·07460	·69256	·02360	·97877	·03336	·48971	·01669	·69209	·02359	2½
3″	5·47839	·26891	7·74758	·38050	3·87381	·19015	5·47837	·26891	2·45001	·12026	3·46482	·17007	1·73242	·08503	2·44999	·12026	·77476	·03803	1·09567	·05378	·54783	·02689	·77475	·03803	3″
3½″	6·05619	·40463	8·56474	·57223	4·28237	·28611	6·05619	·40463	2·70841	·18095	3·83027	·25591	1·91513	·12795	2·70841	·18095	·85647	·05722	1·21121	·08092	·60561	·04046	·85647	·05722	3½
4″	6·55179	·57175	9·26564	·80857	4·63282	·40428	6·55179	·57175	2·93005	·25569	4·14372	·36160	2·07186	·18080	2·93005	·25569	·92656	·08085	1·31036	·11435	·65517	·05717	·92656	·08085	4″
5″	7·47669	1·01948	10·5736	1·44176	5·28682	·72087	7·47669	1·01947	3·34367	·45592	4·72867	·64477	2·36434	·32238	3·34368	·45592	1·74672	·14417	1·49534	·20389	·74766	·10194	1·05736	·14117	5″
6″	8·30098	1·62989	11·73935	2·30502	5·86968	1·15251	8·30098	1·62989	3·71231	·72891	5·24999	1·03083	2·62499	·51541	3·71231	·72891	1·17394	·23050	1·66019	·32597	·83009	·16298	1·17394	·23050	6″
8″	9·76771	3·40957	13·81364	4·82187	6·90681	2·41093	9·76772	3·40958	4·36825	1·52481	6·17779	2·15641	3·09594	1·07820	4·36826	1·52481	1·38136	·48218	1·95355	·68191	·97677	·34095	1·38136	·48218	8″
9″	10·4280	4·60695	14·74742	6·51521	7·37371	3·25761	10·42800	4·60695	4·66354	2·06029	6·59525	2·91363	3·29762	1·45685	4·66355	2·06029	1·47474	·65152	2·08560	·92139	1·04280	·46069	1·47474	·65152	9″
12″	12·18905	9·57326	17·23791	13·50749	8·61896	6·76931	12·18904	9·57325	5·45111	4·28129	7·70903	6·05466	3·85451	3·02733	5·45111	4·28129	1·72379	1·35386	2·43781	1·91465	1·21890	·95732	1·72379	1·35386	12″
24″	17·57926	55·22688	24·86086	78·10270	12·42269	39·05131	17·56836	55·22695	7·86169	24·69819	11·11812	34·92865	5·55905	17·46427	7·86169	24·69825	2·48608	7·81026	3·51586	11·04539	1·75792	5·52269	2·48609	7·81027	24

V = Velocity in feet per second, calculated from formula $V=\frac{k}{2}\sqrt{d\frac{h}{l}}$.

Q = Quantity discharged in cubic feet per second from formula $Q^2=\frac{Kh}{l}\cdot\frac{h}{l}$ = slope as in table above, $\frac{1}{10}$, $\frac{1}{20}$, etc.

N.B.—To find quantity in gallons per minute, multiply discharges by 375.
Quantity in cubic feet per second multiplied by 540000 = number of gallons in 24 hours.

TABLE C.

Table of co-efficient c, for Mean radii in feet.

	Mean Rad. R. Feet.	Co-efficients n of roughness.												Mean Rad. R Feet
		·009	·010	·011	·012	·013	·015	·017	·020	·025	·030	·035	·040	
		c	c	c	c	c	c	c	c	c	c	c	c	
Slope S = ·000025 per unit of length = 1 in 40000 = ·132 foot per mile.	·1	65	57	50	44	40	33	28	23	17	14	12	10	·1
	·2	87	75	67	59	53	45	38	31	24	19	16	14	·2
	·4	111	97	87	78	70	59	51	42	32	26	22	19	·4
	·6	127	112	100	90	81	69	60	49	38	31	26	22	·6
	·8	138	122	109	99	90	77	66	55	43	35	30	25	·8
	1	148	131	118	106	97	83	72	60	47	38	32	28	1
	1·5	166	148	133	121	111	95	83	69	55	45	38	33	1·5
	2	179	160	144	131	121	104	91	77	61	50	43	37	2
	3	197	177	160	147	135	117	103	88	70	59	50	44	3
	3·28	201	181	164	151	139	121	106	91	72	60	52	46	3·28
	4	209	188	172	158	146	27	113	96	78	65	56	49	4
Slope S = ·00005 per unit of length = 1 in 20000 = ·264 foot per mile.	·1	78	67	59	52	47	39	33	26	20	16	13	11	·1
	·15	91	79	69	62	56	46	39	31	23	19	16	13	·15
	·2	100	87	77	68	62	51	44	35	26	21	18	15	·2
	·3	114	99	88	79	71	59	50	41	31	25	21	18	·3
	·4	124	109	97	88	79	66	57	46	35	28	24	20	·4
	·6	139	122	109	98	90	76	65	53	41	33	28	24	·6
	·8	150	133	119	107	98	83	71	59	46	37	31	27	·8
	1	158	140	126	114	104	89	77	64	49	40	34	29	1
	1·5	173	154	139	126	116	99	87	72	57	47	40	34	1·5
	2	184	164	148	135	124	107	94	79	62	51	44	38	2
	3	198	178	161	148	136	118	104	88	71	59	50	44	3
	3·28	201	181	164	151	139	121	106	91	72	60	52	46	3·28
	4	207	187	170	156	145	126	111	95	77	64	56	49	4

TABLE C.—*Continued.*

	Mean Rad. R. Feet.	Co-efficients n of roughness.												Mean Rad. R. Feet.
		·009	·010	·011	·012	·013	·015	·017	·020	·025	·030	·035	·040	
		c	c	c	c	c	c	c	c	c	c	c	c	
Slope S = ·0001 per unit of length = 1 in 10000 = ·528 foot per mile.	·1	90	78	68	60	54	44	37	30	22	17	14	12	·1
	·2	112	98	86	76	69	57	48	39	29	23	19	16	·2
	·3	125	109	97	87	78	65	56	45	34	27	22	19	·3
	·4	136	119	106	95	86	72	62	50	38	31	25	22	·4
	·6	149	131	118	105	96	81	70	57	44	35	30	25	·6
	·8	158	140	126	114	103	88	76	63	48	39	33	28	·8
	1	166	147	132	120	109	93	81	67	52	42	35	31	1
	1·5	178	159	144	130	120	103	89	75	59	48	41	35	1·5
	2	187	168	151	138	127	109	96	81	64	53	45	39	2
	3	198	178	162	149	137	119	104	89	71	59	51	45	3
	3·28	201	181	164	151	139	121	106	91	72	60	52	46	3·28
	4	206	186	169	155	143	125	111	94	76	64	55	49	4
Slope S = ·0002 per unit of length = 1 in 5000 = 1·056 feet per mile.	·1	99	85	74	65	59	48	41	32	24	18	15	12	·1
	·2	121	105	93	83	74	61	52	42	31	25	21	17	·2
	·3	133	116	103	92	83	69	59	48	36	29	24	20	·3
	·4	143	125	112	100	91	76	65	53	40	32	27	23	·4
	·6	155	138	122	111	100	85	73	60	46	37	31	26	·6
	·8	164	145	131	118	107	91	79	65	50	41	34	29	·8
	1	170	151	136	123	113	96	83	69	54	44	37	32	1
	1·5	181	162	146	133	122	105	91	77	60	49	42	36	1·5
	2	188	170	154	140	129	111	97	82	64	54	45	40	2
	3	200	179	163	149	137	119	105	89	72	59	51	45	3
	4	205	185	168	155	143	125	111	94	76	63	55	48	4

TABLE C.—*Continued.*

	Mean Rad. R. Feet.	Co-efficients n of roughness.												Mean Rad. R. Feet.
		·009	·010	·011	·012	·013	·015	·017	·020	·025	·030	·035	·040	
Slope S = ·0004 per unit of length = 1 in 2500 =2·112 feet per mile.		c	c	c	c	c	c	c	c	c	c	c	c	
	·1	104	89	78	69	62	50	43	34	25	19	16	13	·1
	·15	116	101	90	80	71	59	50	40	29	23	19	16	·15
	·2	126	110	97	87	78	65	54	44	32	25	21	18	·2
	·3	138	120	107	96	87	73	62	50	37	30	24	21	·3
	·4	148	129	115	104	94	79	68	55	42	33	27	23	·4
	·6	157	140	126	113	103	87	75	62	47	38	31	27	·6
	·8	166	148	133	121	110	93	81	67	51	42	35	30	·8
	1	172	154	138	125	115	98	85	70	55	45	37	32	1
	1·5	183	164	148	135	124	106	93	78	61	50	42	37	1·5
	2	190	170	154	141	130	112	98	83	65	54	45	40	2
Slope S = ·0010 per unit of length = 1 in 1000 = 5·28 feet per mile.	·1	110	94	83	73	65	54	45	36	27	21	17	14	·1
	·2	129	113	99	89	81	66	57	45	34	27	22	18	·2
	·3	141	124	109	98	89	74	63	51	39	30	25	21	·3
	·4	150	131	117	105	96	80	69	56	43	34	28	24	·4
	·6	161	142	127	115	104	88	76	63	48	39	32	27	·6
	·8	169	150	134	122	111	94	82	68	52	42	35	30	·8
	1	175	155	139	127	116	99	86	71	56	45	38	33	1
	1·5	184	165	149	136	124	108	93	78	62	50	43	37	1·5
	2	191	171	155	142	130	112	98	83	66	54	46	40	2

TABLE C.—*Continued.*

	Mean Rad. R. Feet.	Co-efficients *n* of roughness.												Mean Rad. R. Feet.
		·009	·010	·011	·012	·013	·015	·017	·020	·025	·030	·035	·040	
		c	*c*	*c*	*c*	*c*	*c*	*c*	*c*	*c*	*c*	*c*	*c*	
Slope S = ·01 per unit of length = 1 in 100 = 52·8 feet per mile.	·1	110	95	83	74	66	54	46	36	27	21	17	14	·1
	·15	122	105	93	83	75	62	52	42	31	24	20	17	·15
	·2	130	114	100	90	81	67	57	46	34	27	22	19	·2
	·3	143	125	111	100	90	76	64	52	39	31	25	22	·3
	·4	151	133	119	107	98	82	70	57	44	35	29	24	·4
	·6	162	143	129	116	106	90	77	64	49	39	33	28	·6
	·8	170	151	135	123	112	95	82	68	53	43	35	31	·8
	1	175	156	141	128	117	99	87	72	56	45	38	33	1
	1·5	185	165	149	136	125	107	94	79	62	51	43	37	1·5
	2	191	171	155	142	130	112	99	83	66	55	46	40	2

TABLE D.

Showing loss of Head due to Bends when the Mean Velocity of flow is one foot per second. For other velocities multiply by the square of the velocity.

Radius of Bend.	Loss of head for each degree of change of direction.
Diameter of pipe.	
1	·000025
1·25	·000018
1·5	·000015
2·0	·000013
3	·000011
4	·000011
5	·000011

CHAPTER VIII.

SERVICE RESERVOIRS.

Object.—Position and Capacity.—Open or Closed Reservoirs.—Various Forms of Coverings.—Towers.—Overhead Tanks.—Stand-Pipes.

THE object of a service reservoir is:—(1). To store a sufficient quantity of water to enable the supply to be maintained during repairs to the aqueduct or to pumps. (2). To act as a regulator of pressure in the distributing mains. (3). To enable a fire reserve to be maintained.

The position of clean-water reservoirs is as near as possible to the point of supply, at such a height as will give the necessary supply to all parts by gravitation, and thus avoid pumping. They may be classified as follows:—

1. Reservoirs entirely below ground.
2. Reservoirs entirely above ground.
3. Reservoirs partly above and partly below ground.

No. 1 may be built of masonry or concrete walls; if in rock, only a water-tight facing may be required.

No. 2 may be of masonry or concrete, or may be of earth embankments with puddle cores, or may be iron or steel tanks on masonry pillars.

No. 3 may be as No. 2, or, if built on sidelong ground, may have on the up-hill side simply a water-tight facing.

The capacity of service reservoirs constructed some years ago used to be considerable, *i.e.*, to hold from three to seven days' supply. The advantages of this were that, in case of repairs to the mains, no inconvenience would be caused, and there would be a considerable reserve in case of fire. On the other hand, water, even if filtered, if left unused, may possibly become again full of micro-organisms, and may be, therefore, injurious to health. Hence modern practice has tended to reduce the size of the service reservoir, providing for fire requirements by having a special bye-pass (with unfiltered water, of course) from the main above the filter beds. Although *the supply will be contaminated with unfiltered water* *each time the bye-pass is used*, this is by some supposed to be a lesser evil than that caused by the deterioration of water which has been too long stored after filtration. From 10 to 12 hours' supply is now frequently, therefore, taken as a fair size.

In the opinion of the writer, however, this practice is open to grave objection. Water which has been filtered and kept for a few days *may* have some micro-organisms, unfiltered water is *certain* to have an unknown number, and may be the cause of disease for months after a fire. Hence, the fire reserve water should be filtered, unless there is an entirely separate fire service, which in barracks, at least, is never the case.

The *plan* of the reservoir will obviously be dependent a good deal on circumstances of site, and on whether it is intended to provide a roof. In the case of towers, carrying overhead tanks, a circular form in plan involves the least amount of masonry to contain a given quantity at a given depth. Below the ground the circular form has advantages, in that the curved plan of the walls tends to counteract the thrust of the earth behind, so that they may be built of a more economical section than if the walls were straight on plan; but circular tanks are more difficult to roof, and it is not possible, except by wasting intervening ground, to group several together. It is desirable to group them, or at least to divide them into compartments, so that one may be cleaned while others are in use. This subject will be considered shortly; meantime it is sufficient to say that the usual form is rectangular.

As in the case of settling tanks, the water should be arranged to circulate through the reservoir, so that no part may remain stagnant.

At one large military station the water was pumped from a well into an open reservoir, about 6 feet deep, and then forced through a gravel filter to further storage tanks, the inlet and outlet pipes being close together. This is an illustration of everything that is faulty. The water in the reservoir was stagnant, and, being open to the sunlight, used periodically to be choked with weeds, which grow readily when the water is of a less depth than 12 feet and is free to light and warmth. The filtering material, which was rarely examined, was useless for any cleansing properties, and even if it had been, the pace at which the water was forced through the filter rendered any filtering action quite inoperative. Such an example is only mentioned in order that its arrangements may be avoided.

To promote circulation in the reservoir, it is possible, and is constantly so arranged abroad, to construct interior walls to act as "baffle plates," so that the current passes round them in a zig-zag direction (see *Fig.* 82).

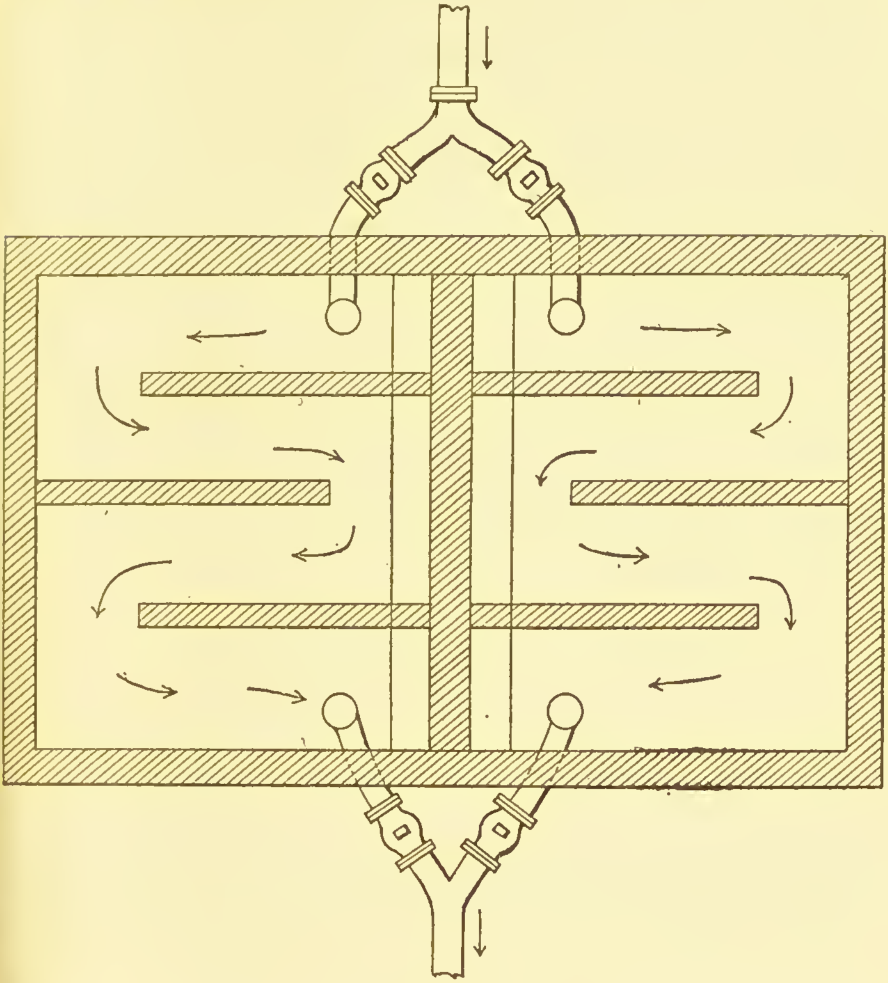

Fig. 82.

As regards the *depth* of water in the reservoirs, those in England vary from 10 to 15 or 16 feet. This depth is necessary, if the reservoir is open. If covered, the depth is not of importance, except for economy of construction. A great depth means less area with a given capacity, but the thickness of the side walls rapidly increases with the depth; hence the saving in cost is inconsiderable, and the risk of leakage greater. On the Continent the depth is often greater than is usual in England, varying from 4 to 6 mètres (13 to 20 feet).

In calculating the thickness of the walls, the graphic method is usually adopted. Where there is no lateral thrust exerted by the roof the top may be about 3 feet thick, and the bottom must be calculated from consideration of the water pressure, acting at a point $\frac{1}{3}$ of the height from the bottom, and equal in amount to $\frac{wh^2}{2}$ where w = weight of a cubic foot of water, and h = depth of the water in feet. This thrust acts horizontally, and the resultant pressure R of the weight of the wall W, acting vertically through the centre of gravity of the cross-section, and this thrust P, must intersect the base of the wall within the centre third of the base (see *Fig.* 83). Where the side walls also bear an arched roof, the thrust of the arch must also be taken into account in estimating the width of the base (see below, *Fig.* 91).

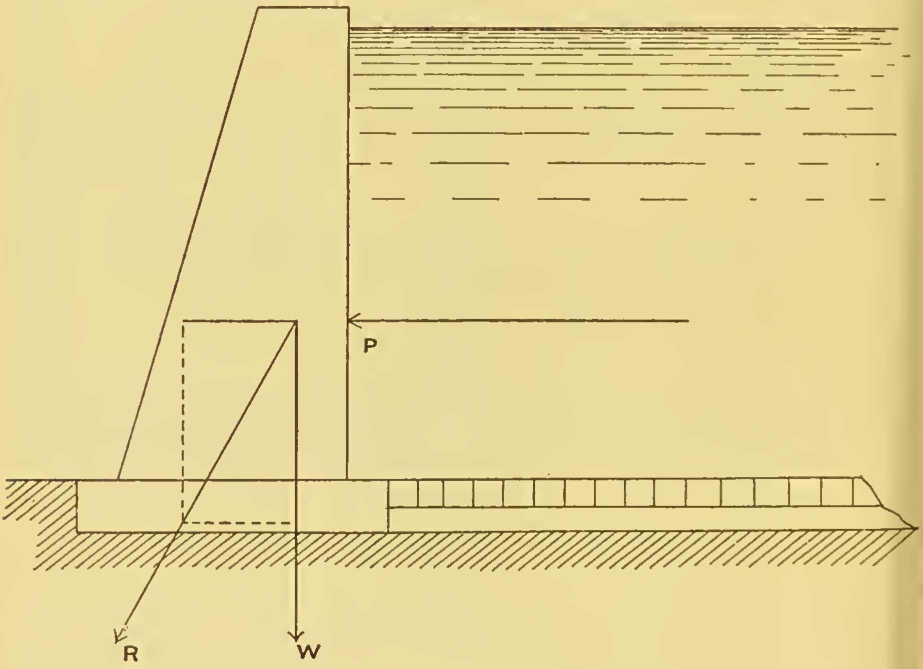

Fig. 83.

Where the reservoir is divided into two by a partition wall, that wall must have a section sufficiently strong to resist the thrust of the water, when one-half of the reservoir is empty.

If built of stone, it is possible to use good hydraulic lime and coarse sand and make a good water-tight job, provided the mortar is thoroughly set before water is admitted (see Appendix IV.). The work should be uncoursed rubble, very carefully packed with spalls, and the best workmanship is absolutely necessary. It is desirable in some cases to render the whole interior face with hydraulic lime, or cement mortar, if cement can be obtained at a reasonable price, but in open reservoirs, where frosts may be expected, ordinary rendering is apt to be disintegrated.

Brick walls are, as a rule, more porous than stone, and have the objection that there is no vertical bond. Brick walls have been frequently used in reservoirs, however, but have been usually rendered with cement plaster, or waterproof paint. White glazed bricks would probably be a good lining.

Concrete has also been much used, and should be a most valuable material where stone is not easily procurable. Concrete blocks on either side laid with horizontal and vertical bond, and filled in with concrete hearting, the whole of the materials being most carefully proportioned, mixed and consolidated, would appear to be the best form to adopt. The interior face should be rendered.

It is often advisable to give a puddle backing to walls of reservoirs, whether of brick, stone, or concrete (see *Figs.* 84 and 85). At the same time, if the latter materials are good, and the work is properly done, there should be no necessity for puddle.

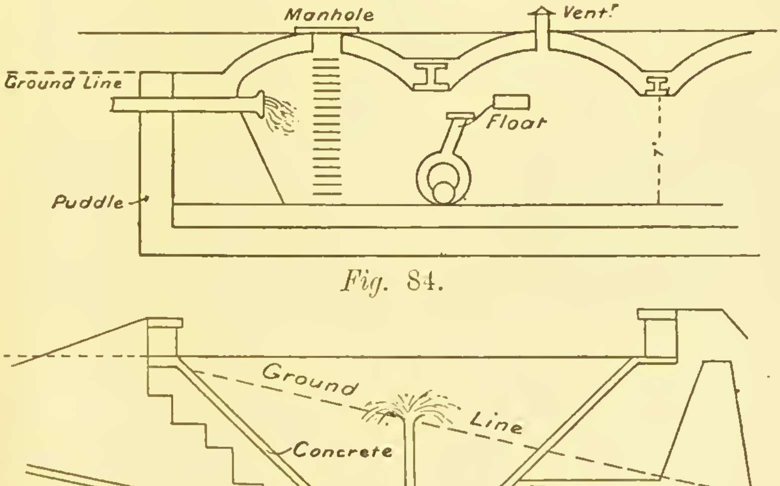

Fig. 84.

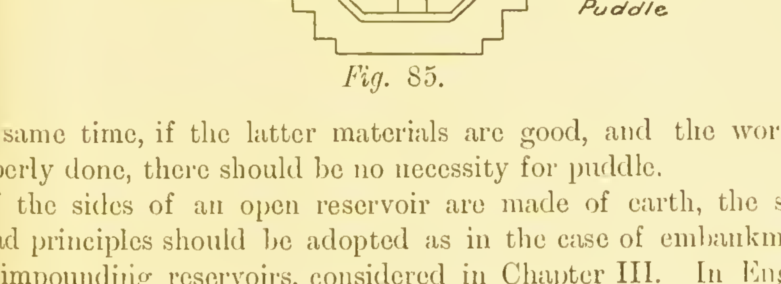

Fig. 85.

If the sides of an open reservoir are made of earth, the same broad principles should be adopted as in the case of embankments for impounding reservoirs, considered in Chapter III. In English practice the puddle core is often omitted, and a facing of puddle given instead on the wetted slope, under stone pitching. In very shallow reservoirs, say up to 12 feet of water, the earth, if of clay or of gravelly loam, may be laid in horizontal layers 6 inches to 9 inches deep, all foreign substances carefully removed, and each layer wetted and rammed, or consolidated with a grooved roller (see the account of the Jeypore dam, Chapter III.), but it is undoubtedly safer to have a puddle core on the general lines indicated in *Fig.* 86.

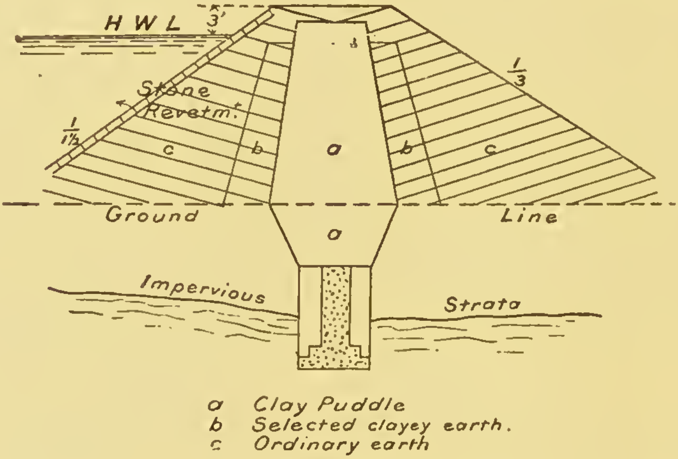

Fig. 86.

A water-tight bank of earth may be made up of the following proportions :—

Coarse gravel	·74	cubic yard.
Fine „	·26	„ „
Sand	·11	„ „
Clay	·15	„ „
	1·26	„ „

giving 1 cubic yard of made bank. The top of the bank may be finished with a parapet wall 3 feet to 8 feet above highest water level, to protect against dust, or damage by waves.

The slopes of the bank may be 1½ to 1, or 2 to 1. The top of the bank should be about 6 feet wide. The floor puddle should be at least 2 feet thick. The thickness of the puddle core should be a minimum of 3 feet at the top, and should have a batter of $\frac{1}{8}$ to $\frac{1}{10}$ to the natural ground, where it should be keyed to a concrete base, as previously described in Chapter III. To protect from rats, the earth next the puddle should be mixed with lime, 10 to 1.

The inner slope of the bank should be protected by stone pitching, carried 3 feet above top water level.

Where the reservoir is in sidelong ground, one side may be cut in steps and filled with concrete, the other may be finished with a wall or embankment, according to materials available (see *Fig.* 85). Frequently earth backing is used outside masonry, brick or concrete walls. This adds to the stability of the wall, and prevents expansion and contraction due to changes of temperature. *Figs.* 87 and 88 show sections of such construction, in a reservoir above ground level.*

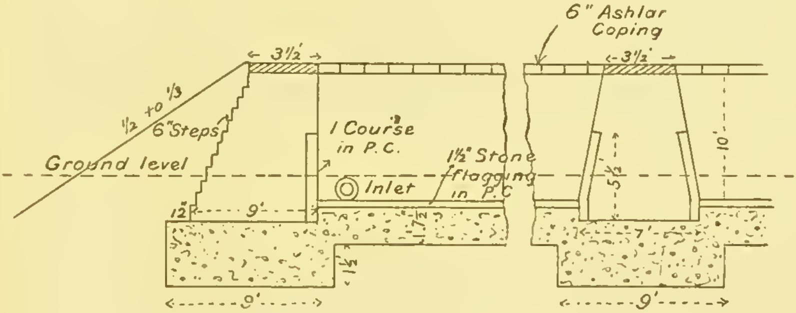

Fig. 87.

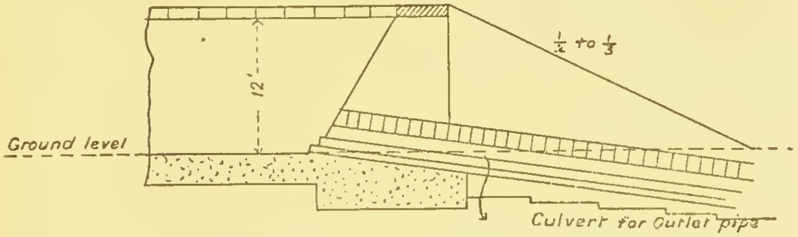

Fig. 88.

The *floors* of reservoirs used formerly to be made with puddle, but of recent years hydraulic lime or cement concrete has been relied upon for water-tightness. Sometimes flagstones laid on concrete are used (see *Fig.* 87), but if there is the least chance of unequal settlement, the flags become loose and the reservoir leaks. The site beneath the floor should be drained so that surface water may not accumulate there.

A *most* important point in connection with the construction of the floors is to give them a slight slope towards the wash-out. If the floor is designed level, the result may be that in actual construction the slope may inadvertently be the other way. This will give endless trouble in cleaning the reservoir ever afterwards.

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* These figures are taken from notes by Capt. A. T. Moore, R.E. (see preface). They are similar to figures in *The Builder*, 1894.

We now come to consider the important subject of *coverings.*

Considerable difference of opinion exists as to whether clean-water reservoirs should be *open* or *covered.* On the one hand, sunlight is a great safeguard against bacteria, the action of the solar rays being one of Nature's methods for purification. On the other hand, it is well known that an open tank under 12 feet or 15 feet deep is apt to become full of vegetation, and whatever the depth may be, it is exposed to particles of dust blown by the wind, or impurities floating in the air, so that the good effects of filtration are to a certain extent done away with. In the neighbourhood of towns where there must be much impurity in the air, the roofing of clean water reservoirs is, therefore, almost universal in England and throughout Europe.

It is not possible to lay down a universal rule. Where the atmosphere is fairly pure and sunlight is abundant, above all, where the supply is originally obtained from a river or a lake, it is generally better to dispense with a roof entirely. But where, as in England, the sunlight is neither powerful nor abundant, where the atmosphere is laden with noxious impurities from factories, etc., it is unquestionably wise to cover over the reservoir, and especially so when the supply has been obtained from a subterranean source.

The usual *method of covering* in England is brick, stone, or concrete arches, resting on pillars which support iron girders, against which the arches abut. Over the arches is a layer of asphalte and 3 feet or 4 feet of earth covering. In some cases the covering is entirely of masonry, built in a series of groined arches. With good materials for concrete, this would be a satisfactory and permanent method. *Plates* XL. and XL.(A) show reservoirs designed by Sir R. Rawlinson, K.C.B. Objection has been taken to the use of iron in plates, trusses, girders, and pillars, because in such situations it is liable to rust and decay. But where iron can be preserved from rust, as in the Monier system, it is a most valuable and economical material for roofing. The Monier system (see *ante,* Chapter V.), although not used in England, has been recently adopted with much success on the Continent. Not only in the roof, but in the side walls, this system can be adopted with the greatest advantage.

Where transverse walls are built across the reservoir, so as to serve as "baffle plates" (see *Fig.* 82), and prevent stagnation of any part of the water, they may be advantageously used for the support of the arched coverings.

Again, it is possible, with considerable economical advantage, to construct the covering and walls in one by continuing the arch structure to the floor line (see *Fig.* 89), showing one built in 1888 at Reichenbach).* An arch uniformly loaded gives a parabolic line of resistance; hence, if the arch ring be built as a parabola, it will require the least amount of masonry in its construction. The pressure of the water within, when the reservoir is full, will produce a horizontal pressure tending to deflect the line of resistance towards the extrados of the arch, and thus the width of the arch ring towards the base must be greater than at the crown. *Fig.* 90

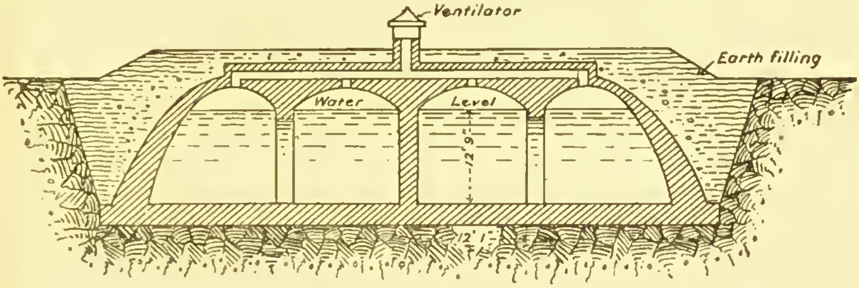

Fig. 89.

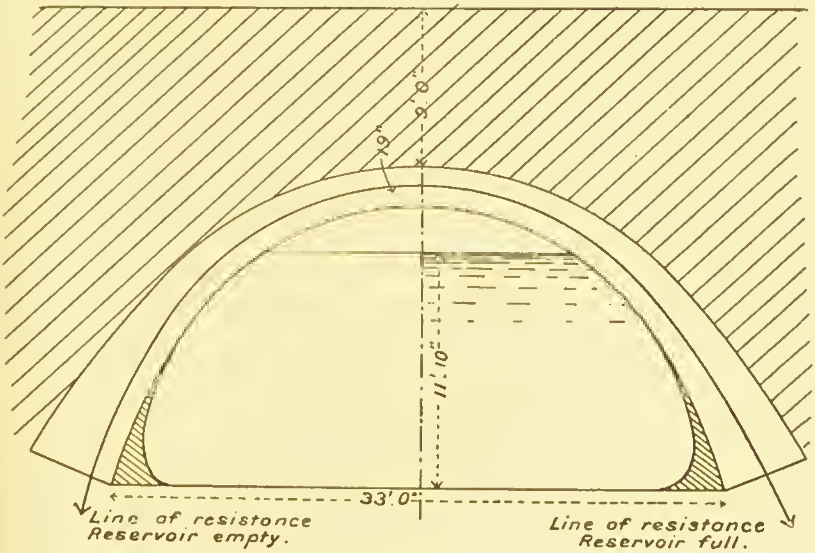

Fig. 90.

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[*] Lueger, p. 760.

shows the position of the line of resistance on the left-hand side when the reservoir is empty, and on the right-hand when the reservoir is full. The thickness at the crown would be estimated by ordinary rules.

Where the arches and abutments are of the ordinary character, it will be evident that the thickness of the latter at the ground line must be greater when the walls are wholly above ground than when they are sunk, or backed with earth. In the former case, as in *Fig.* 91,* there are three forces acting on the abutment—the thrust of the arch Q, the weight of the abutment W, and the thrust of the water P. For stability, the resultant must pass within the centre third of the base. But where, as in *Fig.* 92,† there is earth backing, we have a fourth force T, acting at the back of the wall at $\frac{1}{3}$ of the height of the bank above the base, and (if Scheffler's theory of earth pressure be correct) making an angle with the horizontal equal to the angle of repose of the earth. This force tends to bring the resultant nearer the centre of the base, and, therefore, it is possible to reduce the width, as compared with the former case. The latter is, of course, more usual.

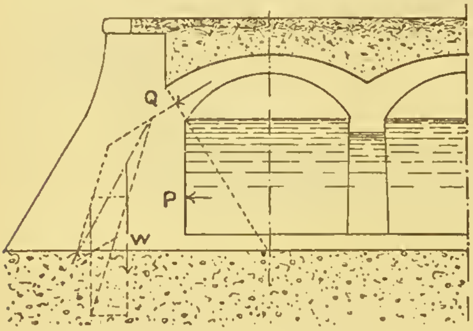

Fig. 91.

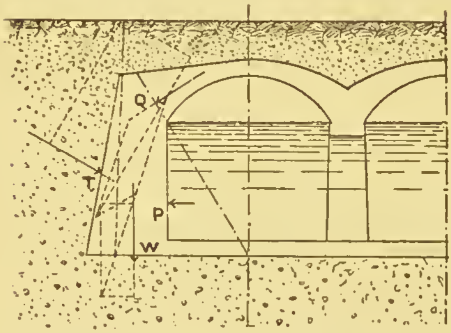

Fig. 92.

Figs. 93 and 94 show an elegant roof of channel iron, concrete, and expanded metal, constructed at Rockford, Illinois. The span was 64 feet (*Engineering Record*, 29th September, 1894).

As regards other arrangements in roofs of service reservoirs, it is sometimes, for economical reasons, desirable to give roofs of slate or tiles, supported in the ordinary way on wooden or iron trusses. Reservoirs of this description may be made with convenient arrangements for entrance and inspection, and they are usually clean and airy. The objection to this form of roof is that it is neither so permanent nor so little affected by changes of temperature as an arched roof.

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* Lueger, p. 765.
† *Ibid*, p. 751.

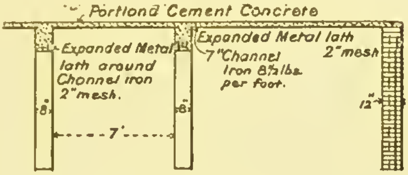
Portland Cement Concrete
Expanded Metal lath around Channel iron 2" mesh.
Expanded Metal lath
7" Channel Iron 8½ lbs. per foot.
2" mesh
8"
8"
7'
12"

Fig. 93.

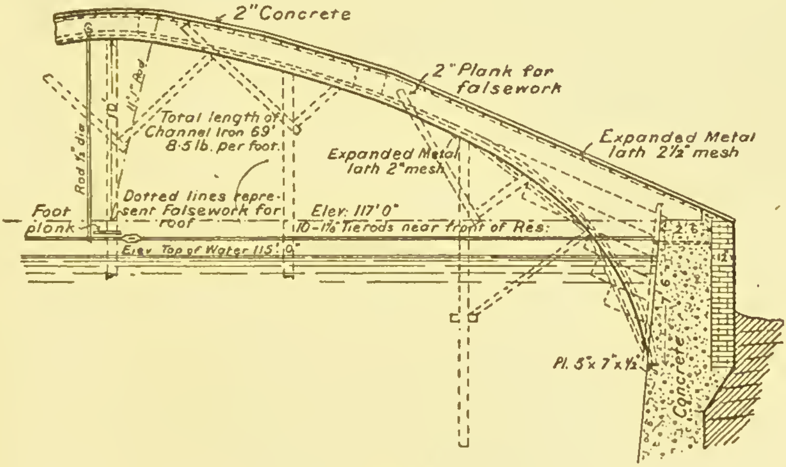
2" Concrete
2" Plank for falsework
Expanded Metal lath 2½" mesh
Total length of Channel Iron 69' 8·5 lb. per foot.
Expanded Metal lath 2" mesh
Rod ½" dia.
Dotted lines represent Falsework for roof
Foot plank
Elev. 117' 0"
10-1⅛" Tierods near front of Res.
Elev. Top of Water 115' 0"
2' 6"
12"
7' 6"
Pl. 5"x 7"x ½"
Concrete

Fig. 94.

In any case, there should be ample *ventilation* in a reservoir covering, and *means of access* for inspection and cleaning. Light should be admissible through windows.

For cleaning the reservoir the whole should be divided by a central wall into *at least two compartments*,* although it is possible, by having a bye-pass that will allow the water to flow past the service reservoir, to manage the cleaning of a reservoir that has no parting division. Of course, this leaves no reserve for fire, as far as the reservoir is concerned.

To determine the *best proportions* for a rectangular reservoir, divided into two compartments, M. Vigreux has pointed out† that if the length of the partition and corresponding sides be y, and if the width of each of the compartments be x, then the most economical arrangement of the sides is when $x:y::3:4$ (see *Fig.* 82).

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* Burton.

† *Projet de distribution d'eau pour une ville industrielle*, Chapter II.

Before leaving the subject of the walls, it may be well to quote the following practical remarks given by Messrs. Turner and Brightmore* :—"When a heavy wall, united to a broad floor, is built upon puddle or other plastic material, it is desirable to build the walls to a considerable height before joining the floors to them. By this plan the risk of the fracture of the floor is reduced. When puddle is used all steps or footings at the back of the walls should be bevelled off, so that in settling the puddle may slide off them and not crack at the angle. . . . When it is carried up in a thin sheet behind a wall, it is desirable to arrange the work so as to lay it as continuously as possible, thus avoiding the many failures that occur from the occurrence of dry and dirty joints in puddle walls."

Position of Inlet and Outlet Pipes.—The *inlet* should, if possible, be placed at one side, near the top, so that the nature and volume of the incoming water can be seen at a glance. In some cases there may be difficulty, owing to loss of head, in bringing the inlet at the top; in such cases it may be brought in at the highest practical level, continued to the centre of the reservoir, and finished with an upright bell-mouth orifice, so as to distribute the water by directing the flow upwards. *Outlets* should be at the opposite side from the inlet, and placed 2 or 3 inches above the floor level, so that any sediment deposited may not find its way into the mains. In open reservoirs the cleanest water is a few inches below the surface; the actual surface being coated with dust, etc., and the water nearer the floor affected to a certain extent by sediment stirred up by the current of the incoming water. To draw off the water from the best level a floating arm may be used, with one end hinged to the outlet pipe, and the other suspended from a float, which keeps the mouth at a fixed level below the surface (see *Fig.* 95, taken from the Glenfield Co.'s catalogue). It will be seen here that the outlet pipe is governed by a sluice valve. This is a necessary adjunct in any case. Outlet pipes should always have a rose head-piece or strainer, to prevent the possibility of leaves, twigs, etc., passing into the pipe. Of course, the area of the perforations must at least be equal to that of the pipe.

Overflows should be provided to all reservoirs, and placed above top water level. They may be connected with the wash-out pipes, and the discharging capacity should be rather greater than that of the inlet pipe. The orifice should be bell-mouthed.

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* *Principles of Waterworks Engineering*, p. 255.

The inlet, outlet, and wash-out pipes of each compartment of a service reservoir should have ordinary sluice valves to control the water, and for convenience the pipes may be brought into small buildings or *valve-houses* adjacent to, but clear of, the reservoir. If possible, the floor of the valve-house should be on a level with the valves, which can then be easily manipulated and inspected by

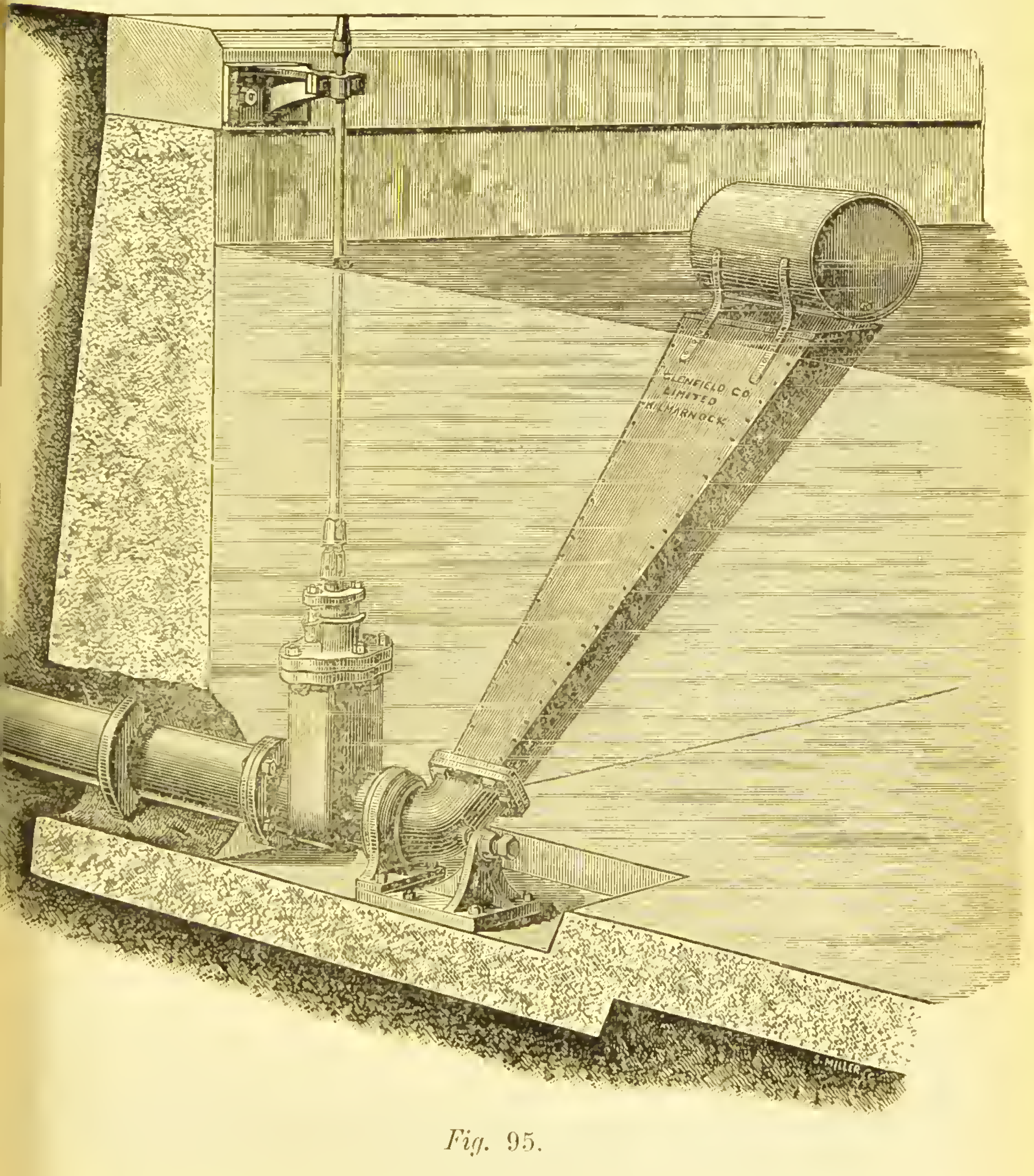

Fig. 95.

natural light. If the floor is on a level with the top of the reservoir, the valves will be in a pit, and artificial light will be required to work them, causing difficulty of inspection, and probable neglect on the part of the attendant. It may be impracticable to have the floors arranged to the best advantage, but the valves in such cases should be worked from above, being provided with connecting rods passing from the floors to the sluices.

If it is necessary to build the valve-house so that one of its walls is a reservoir wall, the latter should be made extra thick, so as to prevent any possibility of leakage into the valve-house, which gives endless trouble. It is much better to build the wall independently and drain the interval. A drain on the floor, near the valves, should carry off any leakage from them.

All valves connected with reservoirs, or where liable to frequent shutting and opening, should be provided with indicators, otherwise they may remain half open or shut, owing to the carelessness of the attendant, without being noticed.

Floating indicators, as in *Figs.* 96 and 97, should be applied to covered service reservoirs.

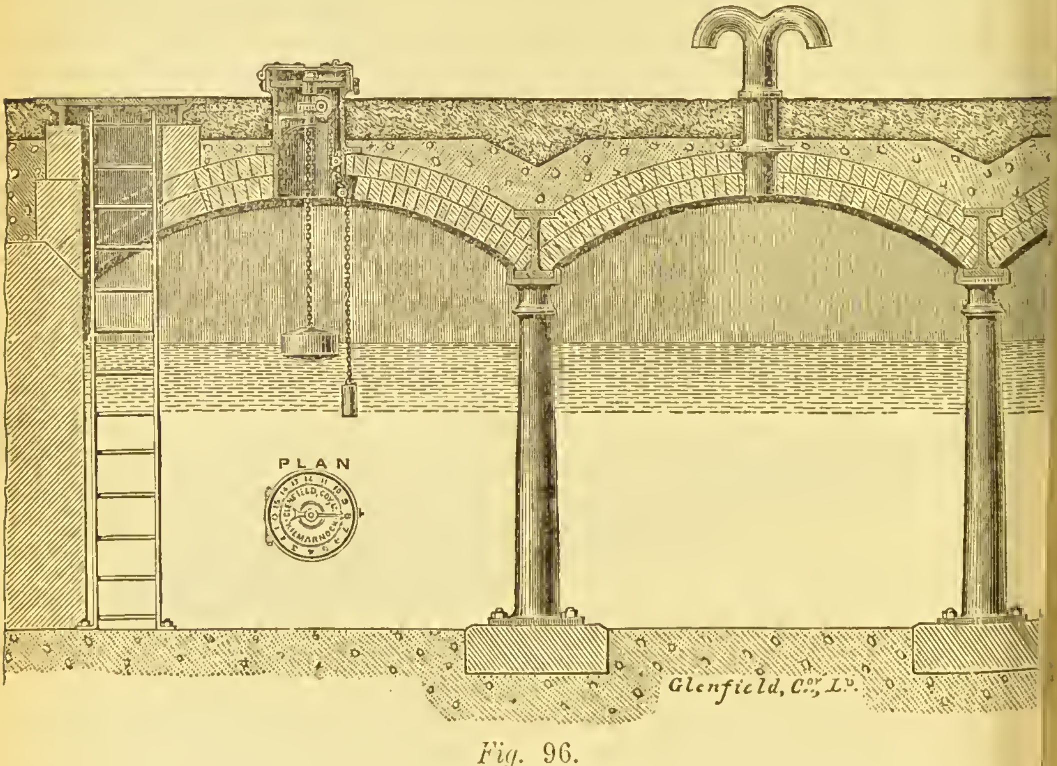

Fig. 96.

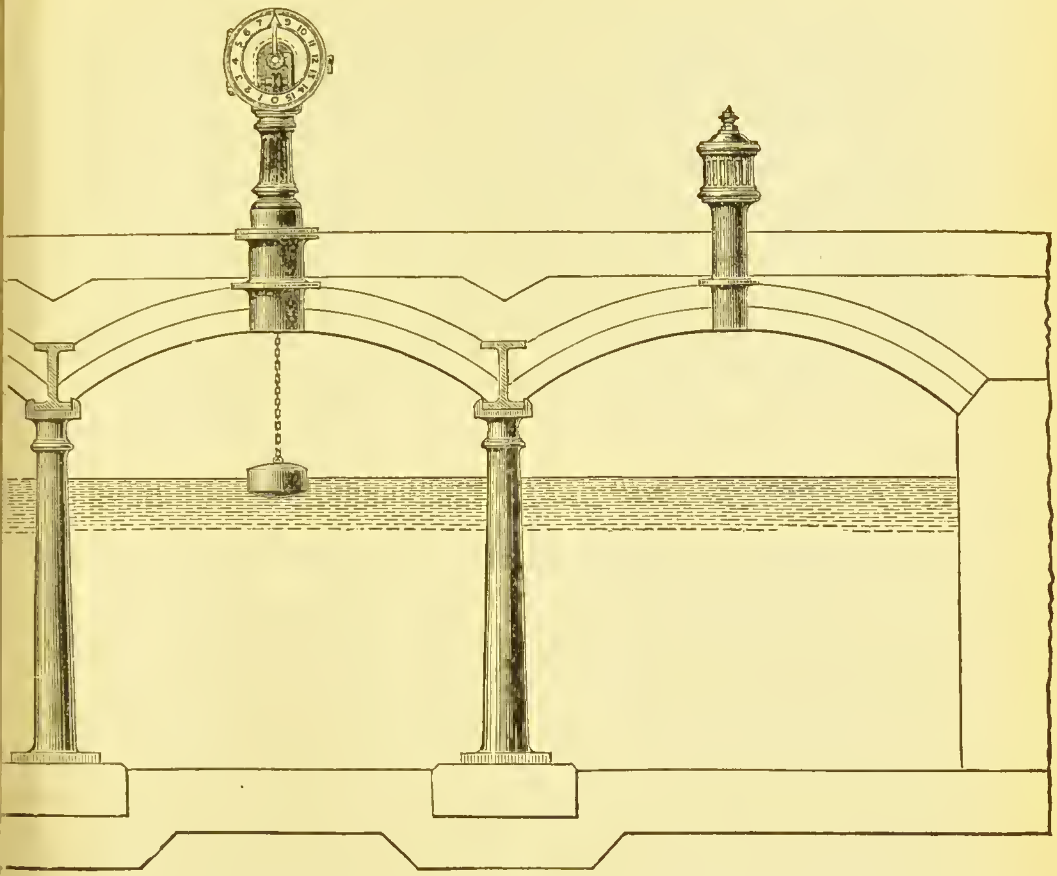

Fig. 97.

IRON TANKS.

Cast-iron tanks are made either square or polygonal, generally of plates with flanged edges bolted together (see *Plate* XLI.). The thickness of the plate, and the depth of the flanges in any given case, can be ascertained from formulæ given in *Molesworth's Pocket Book* (p. 314, Edition 1893). Large plates are stiffened with ribs across the middle, and the flanged ends with angular gussets or feathers.

The plates vary from $\frac{1}{4}$ inch to 1 inch thick. For a tank 8 feet deep, the bottom and lower tier may be $\frac{5}{8}$ inch, and the upper tier $\frac{1}{2}$ inch thick. The size of the plates is 4 feet × 4 feet as a maximum. The joints are generally made by bolting together the flanges of the plates, the bolts being made water-tight with yarn smeared with red lead.

To support the flat surfaces of the tanks against water pressure, horizontal stays from side to side, or diagonal stays from the sides to the bottom are employed, the former generally in small tanks, the latter in larger ones. The former may be either attached to the plates by lugs, or may pass through the plates and be secured by washers and nuts on the outside. Diagonal stays are usually fastened to gusset pieces of wrought iron, which are bolted to the flange joints of the plates by means of the ordinary flange bolts. The bottom of the tank will generally rest on beams or walls, the spacing of which will depend on the depth of the tank and the thickness of the plate. The distance apart of these beams will be found from the equation

$$B = \frac{526t}{\sqrt{D}}.$$

Where B = distance apart of beams.
D = depth of tank.
t = thickness of plates.
All in inches.

For wrought iron,

$$B = \frac{625t}{\sqrt{D}}.$$

The depth of the beams should not be less than $\frac{1}{12}$ span.

The stays should be calculated by estimating the area supported by each stay, and ascertaining the water pressure on that area.*

Tanks of this sort are very common in England, but are gradually being superseded by steel boiler plate cylinders. A still further development, combining strength and economy, has been introduced by Mr. G. F. Deacon, M.Inst.C.E., engineer of the Liverpool Waterworks, to whom the engineering world is indebted for many admirable adaptations of theory to practice.

Taking advantage of the theorem that the intensity of tension in a spherical shell is one-half of that due to equal fluid pressure within a cylindrical shell of the same radius, Mr. Deacon introduced a spherical-bottomed tank requiring neither internal stays nor supporting girders, but simply resting at its edges on masonry. A central shaft with spiral staircase gives access to the top* (see *Fig.* 98).

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* "Hydraulic Machinery" lectures by W. Anderson, M.Inst.C.E., S.M.E., 1878 (R.E. Institute).

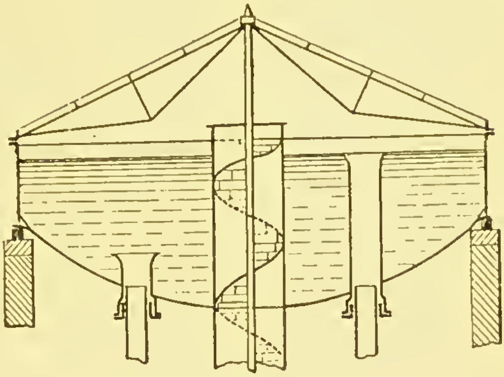

Fig. 98.

Usually, however, such tanks are cylindrical, and are supported beneath on iron or steel girders. *Plate* XLII. shows a wrought-iron tank 61 feet in outside diameter, the details of which were designed by Lieut. (now Captain) E. M. Paul, R.E., at Allahabad. This tank, as will be seen from the plate, rests upon brick piers and concrete foundations.†

This design presents many practical difficulties, which, however, were quite successfully overcome. The construction of radial arches through circular rings involved special arrangements for skewbacks and soffits. The vertical $\frac{1}{2}$-inch boiler plates, of which the sides of the tank were built, were stayed by T-iron diagonals passing to the floor of the tank, and there bolted to the angle-iron stiffeners, which formed the covered plates of the joints of the bottom. The bottom itself was originally designed for lap joints, but as this was evidently an impracticable arrangement, they were fastened by angle irons with butt joints. The floor was of concrete, with an asphalte covering. Each plate was bedded singly in a semi-fluid mixture of tar, pitch and asphalte poured hot on the asphalte flooring, the plates with rivets being pressed down into the mixture while soft, so that the rivet heads sank firmly into the substance below, thus excluding the air, and reducing possibility of rust below; the sides of the angle-iron covers were then bolted up, and the joint filled in with rust cement. The roof was supported by angle irons resting on the edges of the tank, a ring of cast-iron columns, and a centre column of cast iron with special flanges. The whole of these verticals were thoroughly united by cross-bracing. The roof covering was 3-inch concrete. The photograph at the frontispiece shows the finished work.

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* Turner and Brightmore, p. 259, give further details of this design, and state the principles on which it has been worked out. The figure in the text is copied, by permission, from their book.

† The details, lithographed at the S.M.E., can be obtained, on application, by any R.E. officer.

The internal arrangements of a supply tank may be best illustrated by reference to *Plate* XLIII., which represents a fire reserve tank recently erected at Upnor, near Chatham. The supply is not automatic, although it would be quite possible, by means of a floating valve, to make it so. A float, however, acts as a tell-tale, indicating to the attendant when it is necessary to replenish the supply. There is one 4-inch supply pipe, and four 6-inch service pipes, so that the whole quantity may be rapidly available in case of fire. The overflow leads back into the mains. A fire storage is more necessary in small towns than in large, because the same quantity of water would be required in any case for the extinction of the fire, and that quantity would, of course, bear a larger proportion to the total supply in the case of a small community as compared with a large. Hence in barracks and cantonments, which are really small towns, it is not safe to take the rules which apply to large cities when a small increase on the ordinary maximum supply will suffice.

Apart from such considerations, in all places where the site is flat, and the water supply obtained by pumping, it will be necessary to have overhead tanks, so that irregular working of the pumping engines may be avoided. The capacity should be from 12 to 24 hours' supply.

For the preservation of iron or steel tanks, various expedients have been adopted. Generally, they are painted outside with oxide paint, inside with asphaltum coating, or paint, or lined with cement.

In earthquake countries towers should be avoided.

As regards architectural features, it must be conceded that a water tower is a difficult subject to treat æsthetically, and as it is generally a conspicuous object, this fact is to be regretted. To those who may have to design such a structure, Vol. XXI. of *The Engineering Record*, 1891, is recommended. They will find there a series of elegant designs of water towers, from which, no doubt, some ideas could be obtained. A very ornate design for a raised reservoir at Lucknow was prepared by Captain Edgell, R.E., in connection with the water supply for that cantonment.

Stand-pipes is the name applied to structures largely used in America, though not common in English and Continental practice. They combine the functions of a reservoir and a regulator of pressure. They consist of metal cylindrical vertical pipes open to the air at the top, of transverse area at least equal to that of the pipe or pipes flowing away, and full of water from the ground upwards. They are now not so much used as formerly, as air vessels, in connection with pumping engines (see Chapter II.), are relied upon for preventing shocks.

To judge from reports in American papers, accidents from the bursting of these stand-pipes frequently occur, and as the advantages of these structures are not unattainable by other means, it seems hardly necessary here to describe these structures in any detail. Those who wish further information on this subject are referred to Fanning's *Treatise on Water Supply Engineering*, dealing with a subject which is not likely to be much required by those for whom this work is intended.

CHAPTER IX.

VALVES, SERVICE PIPES, AND HOUSE FITTINGS.

Classification.—Sluice Valves.—Reflux Valves.—Throttle Valves.—Pressure-Reducing Valves.—Break-Pressure Tanks.—Air Valves.—Stopcocks.—Service Pipes.—Weights.—Connections.—Joints.—Precautions in Frost.—Meters, positive and inferential.—Cisterns.—Ball Valves.—Taps.

It must be evident that a line of main pipes would be incomplete without the means of control and regulation. To stint the supply of such means is a very false economy.

We come, therefore, now to the subject of *valves*. They may be classified as follows:—

Class I.—Those for *governing* the flow through main pipes.

Class II.—Those through which the water is *delivered* to the consumer.

Both the above include what are called *valves* and *cocks*. These terms are sometimes used indiscriminately to mean the same thing, hence some distinction is necessary.

A *valve* is held to apply to every fitting in which the flow is regulated by (*a*), a diaphragm; or (*b*), a floating ball. These may be worked by a screw, or by a lever, or may act automatically.

A *cock* is held to apply to all apparatus for regulating the passage of water in which the flow is controlled by a metal plug moving with a circular horizontal motion round a vertical axis.

Class I. is sub-divided into:—

(*a*). *Sluice valves* or *gates*, for turning on or turning off water in pipes above 2 inches diameter.

(*b*). *Stop cocks*, a term applied to fittings for controlling water in pipes of less than 2 inches diameter. The term is commonly applied both to those with plugs and those with diaphragms. The latter, however, should be correctly termed "stop valves."

(*c*). *Throttle valves*, for shutting off water automatically in a pipe in case of a burst.

(*d*). *Reflux valves*, for preventing water flowing in the wrong direction.

(*e*). *Pressure-reducing* valves or *relief valves*, for ensuring that the internal pressure shall not exceed certain limits. *Break-pressure tanks* are also used for this purpose.

(*f*). *Air valves*, designed to permit the escape of air automatically from water mains. These have superseded the *air cocks* formerly employed.

Class II. is thus sub-divided :—

(*a*). *Fire plugs*, *fire cocks*, *fire valves* and *hydrants* are terms indiscriminately applied to fittings which have for their common object the supply of water for fire extinction. Formerly the water for this purpose was obtained from an aperture connected with a main and closed by a plug. Such primitive arrangements have long since been superseded by other apparatus, but the name has survived. The correct term is *fire hydrant.*

(*b*). *Bib cocks* and *valves*, commonly called "taps," and in Scotland "crans," are used at the end of a water service for drawing off the water required for domestic uses. These are of many varieties, and are generally described according to their structure or purpose, *e.g.*, *push taps*, *boiler cocks*, etc.

(*c*). *Ball cocks*, or *equilibrium valves* are those which act automatically by means of a floating ball fixed at the end of a lever arm. They are chiefly used in cisterns.

We shall consider the above in detail, though not necessarily in the order of classification. Fire hydrants will be considered in Chapter X., while *service pipes*, *meters* and *cisterns* will be considered in this chapter, as coming under the general heading of *service fittings*.

VALVES.

(1). The first valve that we consider is the *sluice valve*, whereby through the acting of a screw a diaphragm is raised or lowered, admitting or excluding the water from the main. Sluice valves for a large main are shown in *Plate* XLIV. Sometimes there is a bye-pass round the sluice valve, the reason of which will be evident when it is considered how great the pressure must be against the valve when shut. The object of the bye-pass is to admit a small quantity of water to the down-stream side of the valve, and thus equalize the pressure on either side. Sometimes these large valves are made not in one part, but in three, as shown on *Figs.* 1 and 2, *Plate* XLIV. It will be seen from this that the body of the sluice valve is in three parts, with internal strengthening ribs, and the ring piece divides the water-way into three openings, so that the stress upon any one of them is less than the stress on the whole, and thus there is no necessity for a bye-pass. The doors have each independent screw spindles. These valves, however, are only required for very large mains, such as would hardly be used in the case of cantonment or barrack supply.

Up to about 24 inches in diameter it is sufficient to have the valve in one piece, as shown on *Figs.* 3 and 4, *Plate* XLIV. The action of the valve will be evident from these figures. The face of the valve should be of gun-metal, and the socket against which it works should also be of the same material, so that in no place is it necessary for brass or gun-metal to work against iron. These sluice valves are usually fitted with flanged ends, and, of course, require to be fastened to flange pipes. The keys for opening and shutting them can be either as in *Figs.* 5 and 6, *Plate* XLIV., or they may be hand-wheels, as in *Figs.* 7 and 8, *Plate* XLIV., permanently attached to the spindle. The advantage of a wheel is that the valve can be opened without depending on a detached article. Of course, the wheel must be kept secure from any meddling stranger. Very large valves require spur-wheel gearing or other mechanical assistance, which, however, would certainly not be required in the cases which we have specially to consider.

In sluice valves, generally, there are two different methods of raising the disc. In the first method the screw is stationary, and the disc rises up the spindle (see *Plate* XLIV., *Figs.* 1 to 4). In the other case the screw and disc are so attached that the screw rises with the disc. This has the great advantage that the position of the disc is at once indicated by the position of the screw shaft. *Fig.* 99 shows a valve (as manufactured by the Chapman Valve Manufacturing Co., Boston, U.S.A.) which has a yoke above the valve through which the screw shaft rises. If the yoke is not provided, a collar on supports fixed above the box (or some such arrangement) will be necessary.

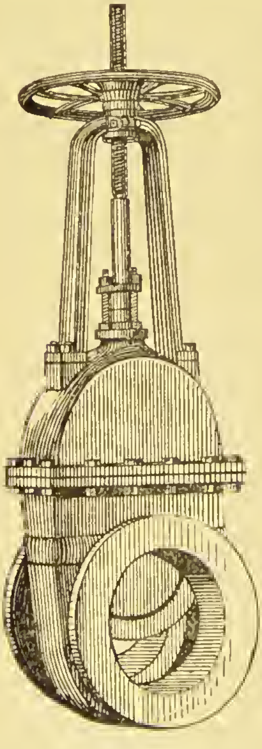

Fig. 99.

Valves with stationary screws must be turned when it is desired to open them in the same direction as the hands of a watch. Valves with rising screws are turned in the contrary direction when being opened.

Valves generally leak through the packing, hence it is advantageous to have a connection between the recess and the pipe on the downstream side.

The valves should be enclosed in masonry pits, properly drained and covered with cast iron road boxes. It is important that they should be protected from rain, and drained, otherwise moisture getting round the valve rusts the bolts and prevents the proper opening and shutting. Where stationary screw shafts are used, indicators (*Fig.* 100) should be fitted to show the position of the disc.

Scour valves or *wash outs* are simply sluice valves placed at low points on the line, connected by a T-piece with the main, and communicating with a drain or water-course, so that the pipe may be emptied when required.

The simplest sluice valves, compatible with due strength of water-tightness, are the best; complicated valves leak and give endless trouble.

For connecting valves with mains, *tail pieces* are used, *i.e.*, short pieces of pipe, made either with a flange at one end and a spigot at the other, or a flange at one end and a socket at the other. In the former case the flange is bolted to the flange of the valve and the spigot, and joined to the socket of the next pipe, and in the latter case the flange end is bolted to the valve, and the socket receives the spigot of the adjacent pipe. Thus the continuity of joints in a line is preserved, and valves can be removed without removing or cutting any pipes.

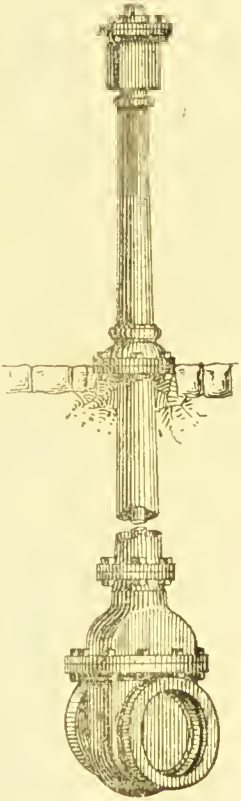
Fig. 100.

(2). *Reflux* or *retaining valves* are shown in *Figs.* 101 and 102.* The object of this valve is to prevent water in a rising main from flowing back again when the pressure is taken off. The simplest form of this (*Fig.* 101), is a shutter or flap hinged at the upper end, which opens when the current flows through in one direction, but falls back and shuts if the current is reversed. The hinged bolt, the faces, and the bushes of these valves are of gunmetal. In *Fig.* 102 the pipe is enlarged, and there are a number of small doors fitted with leather

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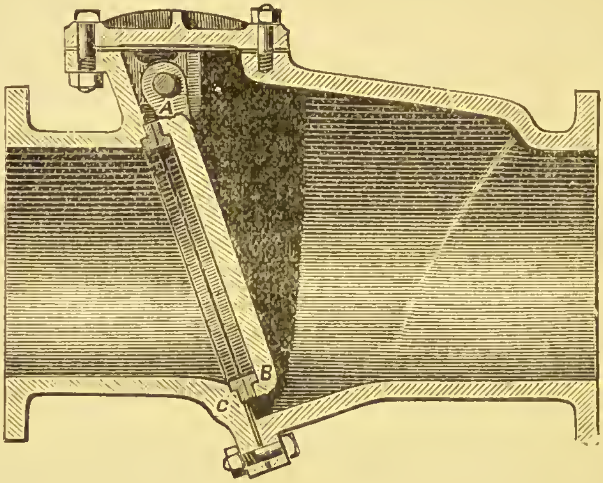
* These, as well as many other figures and plates in this book, are taken from blocks kindly supplied by the Glenfield Co.



A. Gun metal-hinged bolt.
B. ,, ,, face.
C. ,, ,, bush.

Fig. 101.

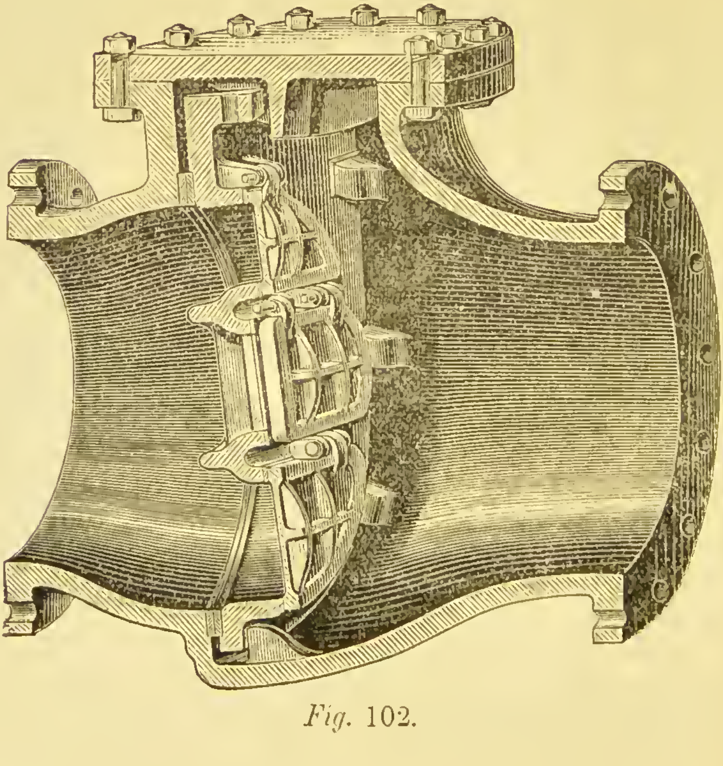


Fig. 102.

faces. It will be seen that, in order to keep the area of the water-way constant, it is necessary to increase the diameter of the bore. These reflux valves are sometimes used with a bye-pass, as in *Fig.* 103, the object of this arrangement being to load the pumping mains

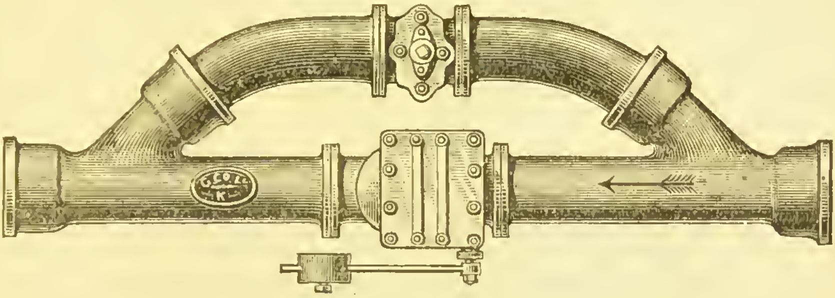


Fig. 103.

so as to supply a high district, while the bye-pass can be used at night or during repairs to pumping engines to supply from service reservoir.

(3). Where the aqueduct consists largely of pipes under pressure, it will be evident that some automatic arrangement is desirable, in case of a burst pipe, to prevent the whole of the water running to waste. This is accomplished by means of a *throttle valve*, drawings of which are shown on *Plate* XLV. This valve shuts off the water gradually in the event of a fracture occurring. The valve itself is placed on a horizontal spindle, and is so arranged that a disc held by a lever and projecting into the water-way is thrown back when the velocity of the current exceeds a certain limit. If the disc suddenly closes the water-way an immense extra pressure will be produced throughout the length of the pipe by the sudden checking of the velocity. This sudden checking is called "ramming," and is, as we have seen before, the principle upon which the hydraulic ram has been devised. Hence it is necessary that in throttle valves the action of the disc or valve enclosing the water-way should be gradual. In order to do this, air cylinders are generally employed, the action of compressing the air having the effect of reducing the closing velocity of the disc.

In the Birmingham waterworks, now under construction, a somewhat similar arrangement, as far as the principle is concerned, has been devised. There a plate, carefully balanced so as to remain vertical while the velocity of the current is within a certain limit, is attached to a chain and trigger in such a way that when the velocity of the current exceeds the necessary limit the trigger is pulled, and a gate or sluice falls gradually into the water-way, obstructing the passage.

On exactly the same principle is the self-closing sluice shown in *Fig.* 104. In this figure A is a disc of size sufficient to resist the

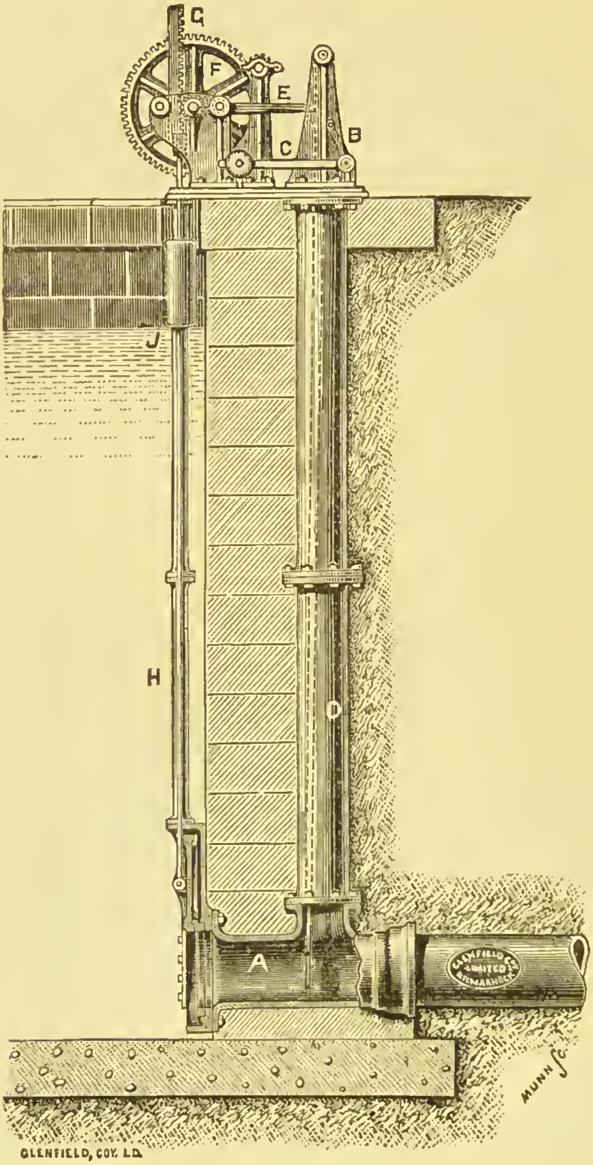


Fig. 104.

pressure due to the normal velocity, and is held in place by the bell crank B, and is balanced by the weighted lever C. The rod D attached to the disc A, has a projection forged on it, on which the end of the lever E rests, and the other end is held up by a lug cast on the pinion F. This pinion gears into the rack G, to which is attached the rod H from the sluice door. On this rod is fixed a weight J, which pulls down G, causing the lug on the pinion F to exert an upward force on the short end of lever E, and so making the long end of this lever to bear tightly on the projection D. Therefore, so long as A is its normal position the whole arrangement is locked and the sluice cannot close. When the velocity of the current is so great as to force the disc outwards, the projection on the rod D is withdrawn from the lever E, which drops, releasing the pinion F. The weight J then pulls down H, shutting the sluice door.

(4). In all long lines some arrangement must be made to equalize pressure. Thus if the supply to a community passes through a long line of delivery pipes from a pumping station, it will be necessary to provide either relief valves, or a raised reservoir, into which the water is directly pumped, or, as in America, a stand pipe. If none of these precautions are taken, throbbing will take place, and burst pipes inevitably result.

Escape or *relief valves* are for allowing water to escape when the pressure exceeds certain limits. They are, like the safety valve of a steam engine, usually valves weighted so as to open at pressure greater than the weights. They are specially of use on long lines of pipe.

Several kinds of *pressure-reducing valves* have been devised. In all cases the object is to reduce the pressure within certain limits inside the pipe. *Fig.* 105 shows such a valve, as constructed by the Glenfield Co. The valve consists of a partition E (with openings up and down stream), in which is fixed a brass cylinder F, with ports DD, equal or greater in area than the pipe. In F there is a double piston AA, connected with an upper piston B, which, in its turn, communicates with a 3-way cock at L. In the figure the valve is closed; no water is passing. When it is open the pistons AA fall, and water passes out at the top and bottom. The inner side of the valve is connected by cocks C and R with the relief valve at L. This valve may be set to open at any maximum pressure, so that if the actual pressure exceeds that maximum, the relief valve will discharge water. As the relief valve and top of the piston B are in communication, the pressure on the top of B cannot exceed the maximum pressure to which L is set. When a draw-off takes place the pressure on the outlet falls, and as the pressure on B remains constant, the piston with valves AA is forced down, opening the valve. When the draw-off ceases, the pressure on the underside of B rises again, forces up the piston and shuts the valve. The valve closes when the pressure on the down-stream side attains the point to which the valve is set to work at, re-opening when the pressure falls below that point. Thus the down-stream pressure is practically constant and independent of varying pressures above. In some cases it is sufficient if the valve acts simply as a regulator, and does not necessarily require to shut off the water tight. In others it is required that the water be shut off absolutely when the pressure attains a given point. If desired, a lever can be fitted to put the valve out of action when the full head is required, as in case of fire.

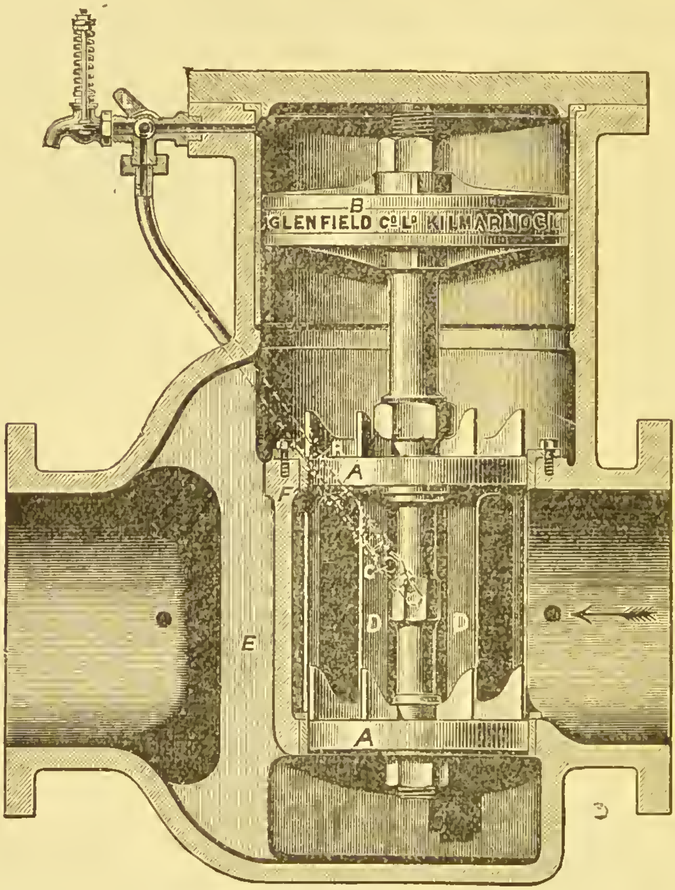
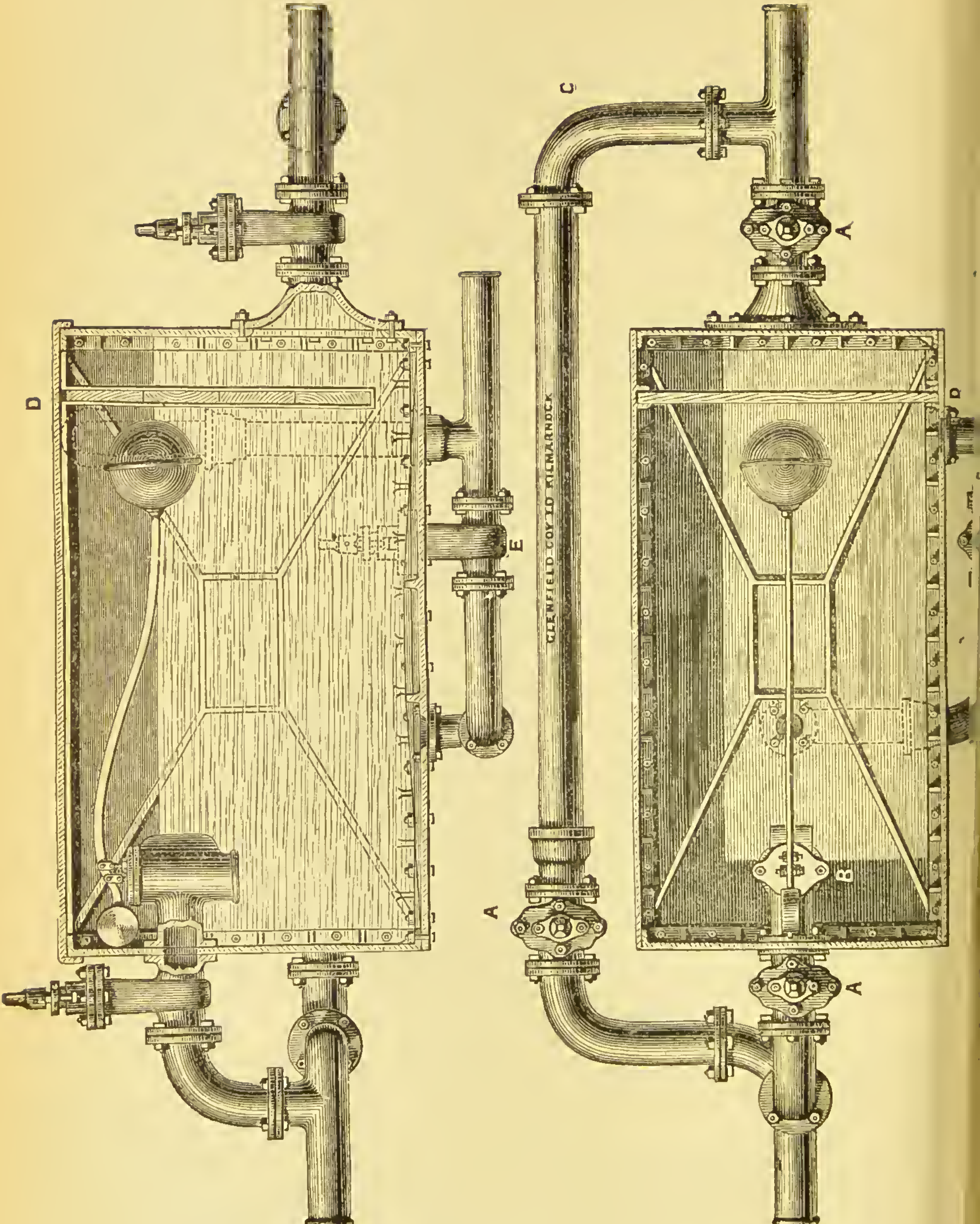


Fig. 105.

While on the subject of pressure-reducing valves, it is necessary to say something about *break-pressure tanks.* These are used on the mains to dispose of excess head beyond requirement, to reduce the pressure, and thus to save thickness in pipe. They may be of masonry with arched roofs, the water coming in at one end and passing out at the other without any pressure, in which case they become balancing reservoirs (see Chapter V.). The inlet and outlet pipes may be at the same level; the mouth of the outlet pipe should be covered by a strainer, and should be furnished with a sluice valve. There should be access to the interior for cleaning, and a window for ventilation and light. The floors should be sloped and provided with a wash-out, and an overflow should be provided to carry off any water when the forward pipe has become full on account of any accidental stoppage or the closing of a valve. On distribution mains, break-pressure tanks are of iron, somewhat as shown on *Fig.* 106. The inlet is provided, as will be seen, with an equilibrium ball valve B to stop the supply when the forward pipe is full. The bye pass arrangement C is not absolutely necessary, but is generally found convenient. The tank can be cleaned at any time by emptying it from the bottom by the pipe and valve E placed there for the purpose.

In the event of the ball valve B becoming clogged by foreign matter, causing leakage to a slight extent, the overflow of water is carried into the emptying pipe by a bend E. At the end of the tank there is a wooden partition D to prevent the backwash of air which might come from the forward pipe and agitate the water in the tank.

(5). In all mains a certain quantity of air frequently collects while pipes are being filled with water. Sometimes, also, air accumulates when the pipes are full of water. *Air valves,* therefore, are necessary to allow of the escape of what would otherwise prevent the passage of the water altogether. Air valves may be single or double; they should be placed at the highest points of a pipe line. The single valves are for small quantities of air which accumulate near the tops of bends. They consist of a small floating ball of cork or gutta percha, which, as long as there is air in the pipe, will lie at the bottom of the socket; but when the pipe is full of water the ball will float on the surface, and will close up the aperture at the top of the chamber through which the air has been escaping, as shown in *Fig.* 107. Double air valves are frequently used, as shown in *Fig.* 108, the larger of the two outlets being intended for the



AA. Sluice valves.
B. Equilibrium valve.
C. Bye pass.
D. Wooden partition.
E. Valve for emptying.

Fig. 106.

escape of large quantities of air, and the smaller for any little quantity that may have accumulated when the pipes are full.

It is usually necessary, and always advisable, after a system of distribution mains has been laid, and before house connections are made, to "wash out" the mains, and so remove grease, sand and impurities which have accrued. To do so dead ends and scour valves are opened, and the water tested every hour until free from impurities. If possible, the attachment of meters should be deferred till after this is complete, lest sand enter the working parts to their detriment, and also to enable the record of consumption to start fair as zero. When water is admitted to pipes for the first time, it should be let in gradually. If there are not air valves on any part of the line, taps should be opened to allow air to escape.

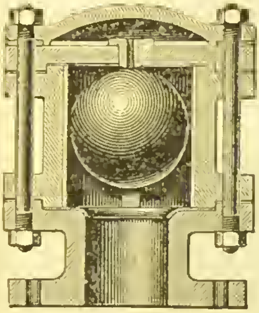


Fig. 107.

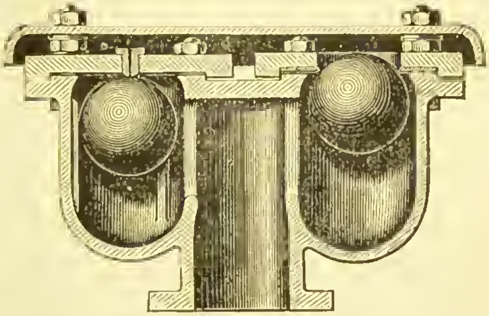


Fig. 108.

(6). *Stop-cocks* differ only in degree from sluice valves, being the regulator used generally on supply or service pipes. The difference between a sluice valve on a main and a stop-cock on a service pipe, generally, is that the sluice on a main pipe works vertically, and a stop-cock on a supply opens a horizontal orifice, as shown on *Figs.* 109 and 110,* which represent Messrs. Stone & Co.'s "patent constant-supply double-valve screw-down stop-cock." It will be seen from these figures, one of which represents a valve shut and the other open, that there is a double security against leakage when closed. Both valves are securely held upon their seatings by the screw spindle at the same time. It is also easily repairable, and is, therefore, specially adapted where there is a constant supply of water, because the upper parts can be taken away and repaired while the lower valve is securely held against the seating by the pressure of the water.

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* This and several other figures are from blocks kindly lent by Messrs. J. Stone & Co.

This stop-cock has been adopted by all the principal London

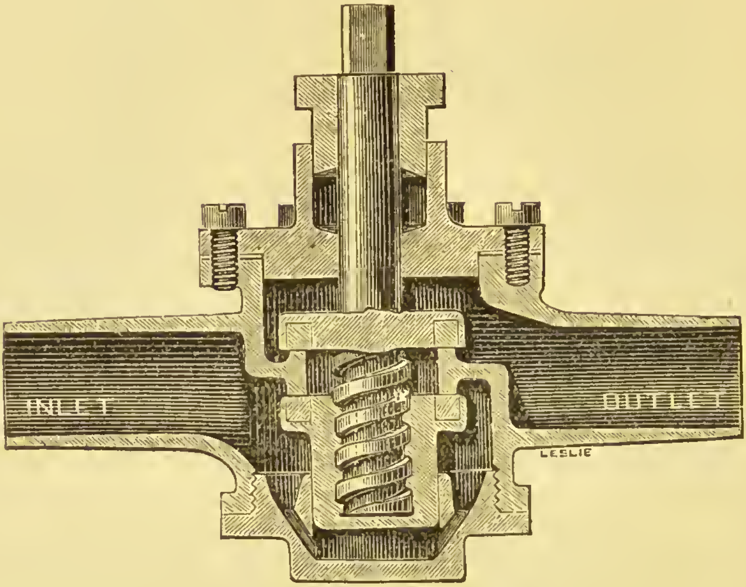

Fig. 109.

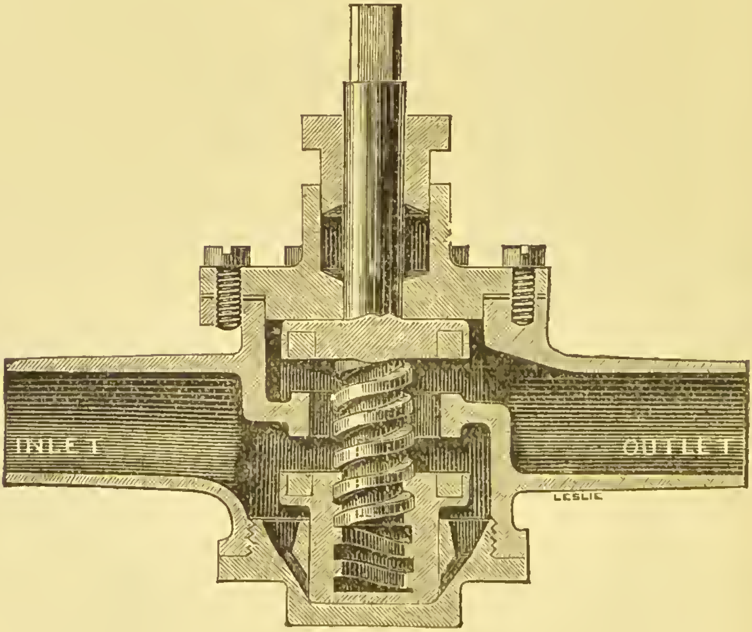

Fig. 110.

water companies. The spindle is generally worked by a key with a T head, the whole being situated in a small pit below the surface of the ground, but it may be fixed in any other desired position, and can, if necessary be worked by a wheel-handle.

SERVICE PIPES.

The intense frost of 1895 will long be remembered for its effect on water pipes, and the great inconvenience thereby caused to householders. The following are a few of the maxima depths at which mains were then frozen:—Hereford, 3′ 6″; London, 3′ 2″; Tamworth, 3′ 3″; Twickenham, 3′ 4″. Some mains, at nearly 4 feet in depth, were found full of ice at Cheltenham, but there appears to have been some special reason for this.

In nearly all cases the mains which were frozen were under 6 inches in diameter.*

It is advisable, when attaching service pipes to mains, not to form the connection at the top, as would be done in a gas service. By forming the connection at the side of the main, a greater covering of earth, and protection against frost, is secured.

Service pipes, when let in on the top of the main with a quadrant bend, should be 2 feet 6 inches below the surface, and this is the least depth where in this country they will be usually free from the action of frost.

Service pipes may be made either of lead or of wrought iron. Pipes of 2-inch bore and under should be of strong wrought iron lap-welded, tapped with screwed socket joints, put together with red or white lead. As a rule, the diameter of pipes used varies from 1½ inches to 1 inch, but smaller pipes are used for the supply to w.c. apparatus and urinals.

The joints in wrought-iron service pipes may be formed in two ways. The first is by having a sleeve or collar, in which are cut both left and right-handed screw threads, so that when passed over the ends of the meeting pipes, it tends to draw them closer together. The second, and preferable, method is to have the collar cut with the ordinary right-handed thread throughout, and to have the screw on the *pipe ends* slightly tapered, so that the joint when screwed up gets tighter and tighter. If the screwed end is not tapered, it may be wrapped with spun yarn. Where a length of pipe is introduced into a system, a *connector* is used, *i.e.*, a short piece of pipe, one end of which has a parallel screw thread cut upon it, of a length sufficient to admit of the collar or socket running its full length upon it (see *Figs.* 111, 112 and 113). This joint is made tight with a piece of gasket and a back nut. It is desirable to introduce these connectors

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* Quarterly Journal, Royal Meteorological Society, July, 1895.

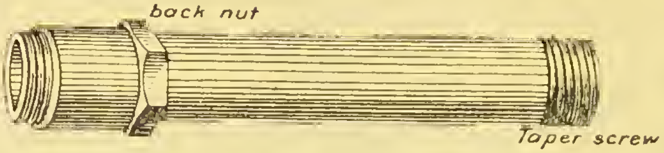


Fig. 111.

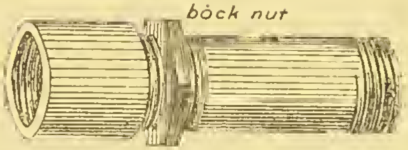


Fig. 112.

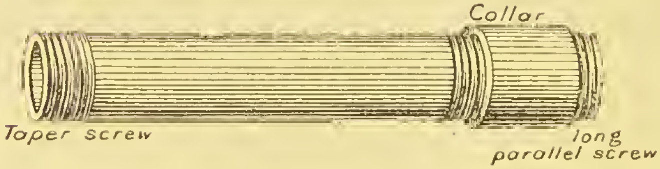


Fig. 113.

at intervals in a building, to avoid cutting a pipe when new branches are required.

The sudden shutting off of the flow of water in the pipes may cause the screw threads in connections to strip.

As the subject of screw threads is important in this branch of the subject, it may be well to point out that there are three distinct sets of stocks, taps and dies used by workmen :—(1). *Whitworth's*, for solid articles, with deep threads, used by fitters and smiths. (2). *Barrel*, used for iron pipes, with medium threads, used by plumbers and gas fitters. (3). *Brass*, for brass tubes, with fine threads, used by gas fitters.

The following tabular statement of the diameters, thicknesses, weights, etc., of various wrought-iron pipes has been obtained from various manufacturers' publications, and may be useful :—

Tabular Statement of Thicknesses and Weights of Wrought-Iron Pipes.

Internal diameter...	⅛″	¼″	⅜″	½″	¾″	1″	1¼″	1½″	1¾″	2″	2¼″	2½″	2¾″	3″
Gauge	12	12	11	10	9	8		6	6	5	5	5	5	5
Thickness, inches ...	·104	·104	·116	·128	·144	·16	·176	·192	·192	·212	·212	·212	·212	·212
Do., millimètres ...	2·6	2·6	2·9	3·2	3·6	4·06	4·47	4·87	4·87	5·38	5·38	5·38	5·38	5·38
Weight per foot run. lbs.	0·3	0 44	0·67	0·94	1·48	2·03	2·92	3·59	3·97	5·04	5·74	6·29	6·85	7·40

In the above the pipes are butt-welded up to 1$\frac{3}{4}$-inch diameter, and lap-welded for 2-inch diameter and over.

These thicknesses and weights are tabulated from information kindly furnished by various manufacturers, and are sufficient to stand about 500lbs. pressure per square inch, or upwards of 1,000 feet head. If the required pressure be less than this, say 200lbs., or about 500 feet head, the thickness in each case may be made one gauge less. Galvanizing tubes increases their weight from 3 to 6 per cent.

There is no reason, however, why galvanizing should be resorted to in water pipes. If treated with asphaltum, as previously described in Chapter V., black wrought iron should answer all purposes of service pipes, and there would be no hygienic objection, as there would be in the case of galvanized iron.

Changes in direction of wrought-iron pipes are effected by bends, *i.e.*, quadrants, "springs" (the trade name given to bends at obtuse angles, as in *Fig.* 114), elbows, T's, and other rectangular junctions. Changes in direction should be as gradual as possible.

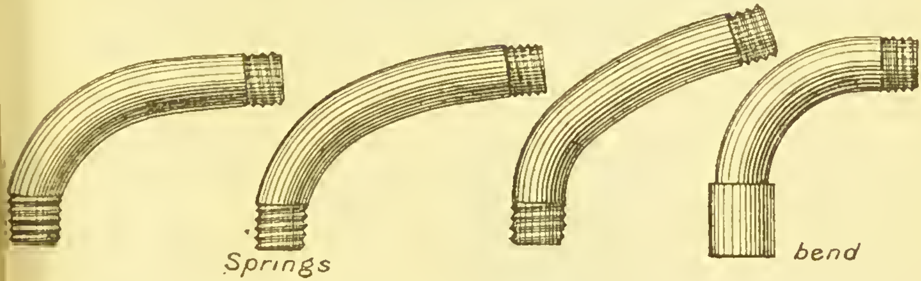
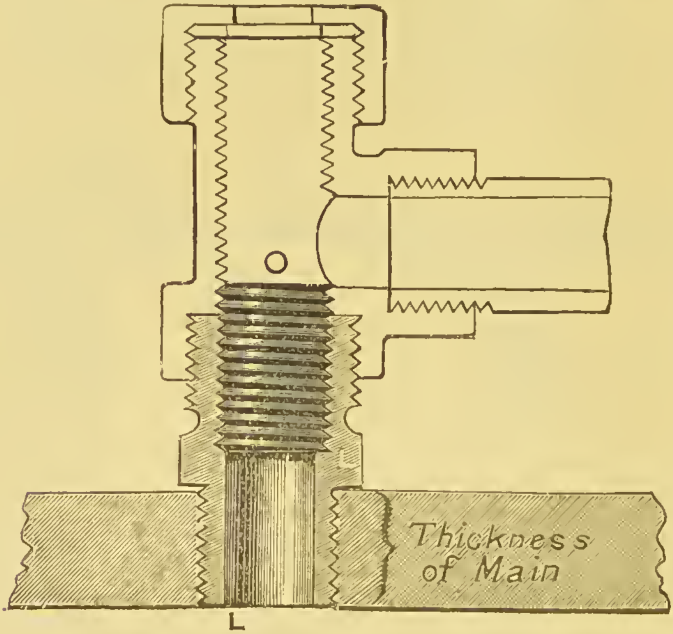


Fig. 114.

The connections between service pipes and cast-iron mains is made by drilling a hole of the required diameter into the main by means of a ratchet brace and cramp.

This is done when the pipes are full by the use of the "Morris's apparatus," shown on *Plate* XLVI., manufactured by J. Stone & Co. A packing piece A is placed on the pipe at the required spot, the joint between the packing piece and pipe being made by greased felt, etc. The saddle B is then fixed in position by the chain C, and the slide D is placed with the hole in it over the required spot. The spindle E, with drill tap attached, is then inserted in the boss on B, and the internal sleeve F is slipped over the spindle E. Both E and F are furnished with cup leathers, to prevent leakage. The outer sleeve G is then screwed on to the saddle piece, and cramped.

The double ratchet K is then placed in position, tightened up, and drilling is commenced, tightening up H when necessary When the drill is through the main, the tap and drill is withdrawn by reversing the pin in the pawl of the ratchet, and the slide D is closed. The drill tap is then removed from the socket E, and in its place is inserted a screw-plug M, which projects below the spindle socket, and to which plug is screwed the lower part of ferrule L. When fixing ½-inch and ¾-inch ferrules, the socket N is used, the top part of which is screwed to the bottom of M, and the lower part over the lower part of L. The spindle, with these attachments, is again inserted as before, and, after the slide D is withdrawn, the lower part of the ferrule is screwed into the hole. Then the whole of the apparatus is removed, leaving the lower part of the ferrule, as in *Fig.* 115 (or L, *Plate* XLVI.), in the main. The upper part of the ferrule is then screwed on to the part left in the main (*Fig.* 115), and the outlet connected with the service pipe. The plug valve O can then be opened by a spanner. *Fig.* 116 shows valve open.

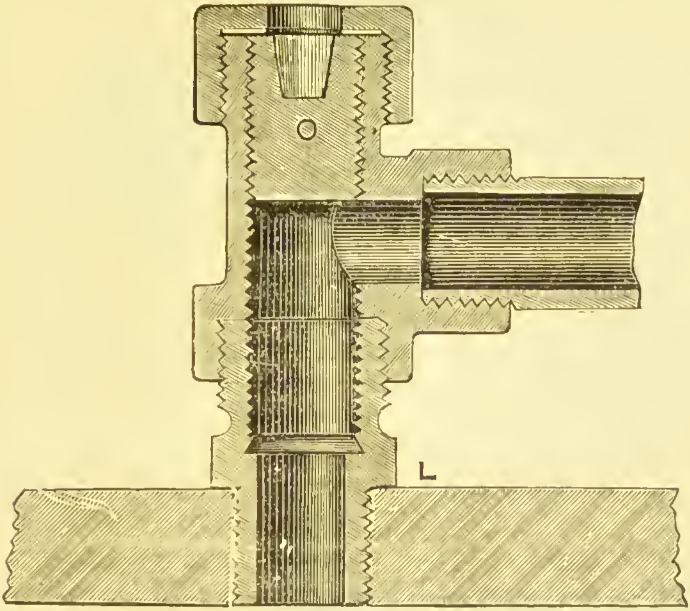


LL. Ferrule.
O. Screw plug.

Fig. 115.

This method enables a main to be tapped and connected with a service connection without cutting off the supply.

It is, of course, desirable that the positions of all service connections should be settled when the mains are being laid, when the tapping can be carried out without any special apparatus. It is not always possible to foresee all requirements, so tapping mains under pressure may be inevitable.



L. Ferrule.
O. Plug.
Fig. 116.

Where a main pipe has to supply rows of houses, as in a street, it is better to take the service pipes from a *rider main* (in barracks, say 3-inch diameter), running parallel to the other, and controlled by sluice valves at each end. It will thus be possible to cut off the supply from the group of houses without affecting the whole.

Lead pipes are in many cases preferred to wrought iron, because easier to bend, and less liable to corrosion. They are generally specified to be a certain weight per lineal yard (see Specification, Appendix II., para. 88). If required to stand a pressure greater than that due to about 150 feet head, the weights must be increased.

The usual joints for lead pipes are :—(1). *Wiped* joints, of the ordinary description, which, however, tend to obstruct the bore (2). "Clear-bore" joints (*Figs.* 117 and 118) made with an interior brass ferrule, the joint being enclosed in a mould, and hot solder run in, until the space outside the ferrule between the ends of the pipes is completely filled in.

There are, besides, certain composite joints between lead and iron pipes, or for uniting iron pipes without solder, in which brass ferrules are used. *Fig.* 119 shows two ends of lead pipes upset, or coned out, covered by a ferrule, on which is screwed a socket, both of brass. Between the upset ends of the lead pipe is a leather washer. *Fig.* 120 shows a section, and *Fig.* 121 an outside view of

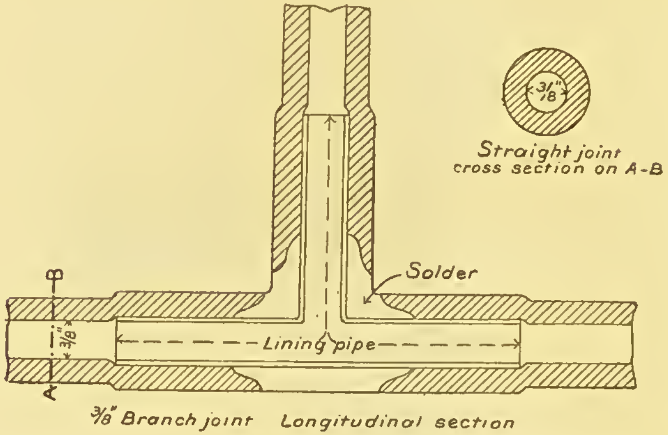


Fig. 117.

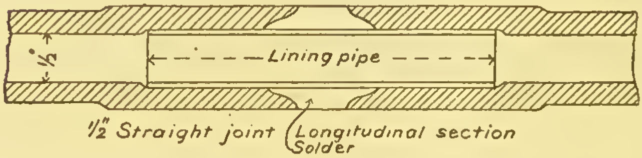
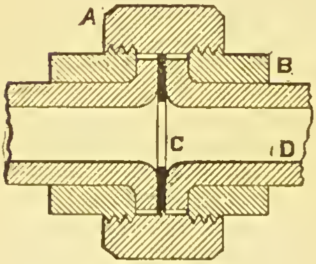
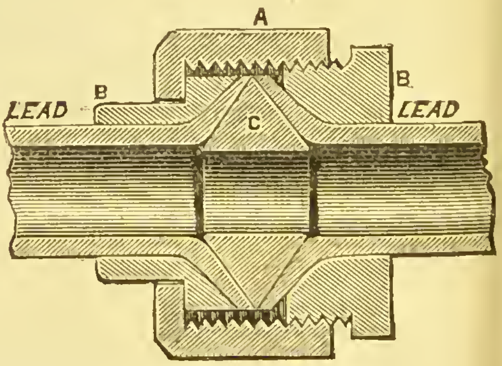


Fig. 118.



A. Brass socket,
B. ,, ferrule.
C. Leather washer.
D. Lead pipe

Fig. 119.



A. Brass cap or collar.
B. ,, ferrule.
C. Cone.

Fig. 120.

a "cone joint" for uniting lead pipes without solder. The cone piece should have a circular opening at least equal to the bore of the pipe (in *Fig.* 120 it is shown smaller than the bore). The brass unions are slipped first over the ends of the lead pipe. The ends of the lead pipe are then opened out, the cone piece inserted, and the two parts of the brass unions screwed together. *Figs.* 122 and 123 show the same principle for connecting a lead with a wrought-iron pipe. *Fig.* 124 is a brass elbow union, one end having a cap and lining,

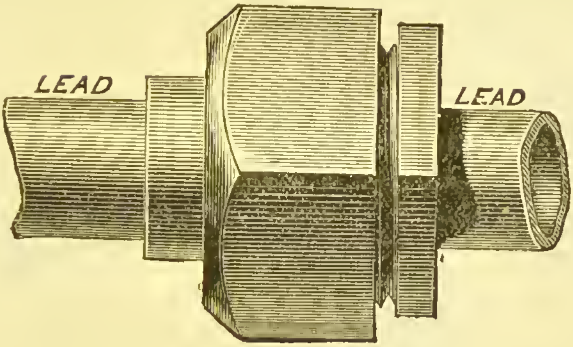
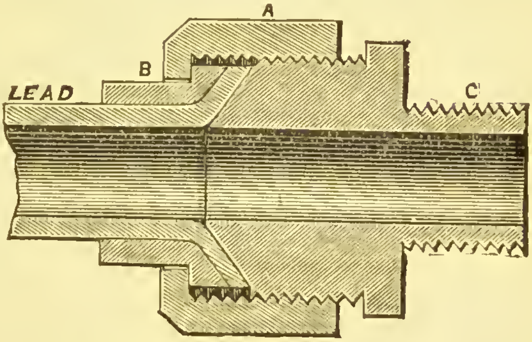


Fig. 121.



A. Brass collar.
B. ,, ferrule.
C. ,, Cone screwed for iron

Fig. 122.

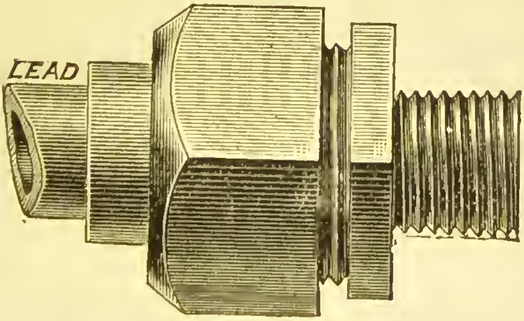
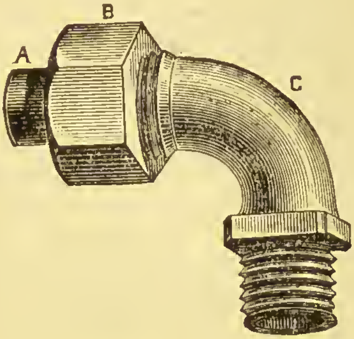


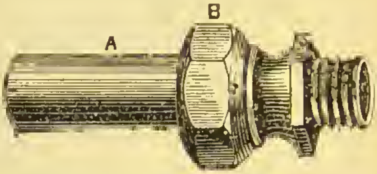
Fig. 123.

with tinned end for lead; the other end has a thread for connecting with an iron pipe. *Fig.* 125 is a straight union for joining lead to iron, and is a better form than *Fig.* 126, which is one solid brass casting, whereas *Fig.* 125 represents a union joint in two parts, screwed together at the cap. *Fig.* 127 shows a brass ferrule, with screws at both ends, which may be used for iron pipes, instead of the ordinary "spring" bend. *Fig.* 128 is a specially strong brass union, for connecting lead with iron. One end is tinned for soldering on the lead pipe, the other end has a nut to screw on to the end of the iron pipe. *Fig.* 129 shows a stop-valve



A. Tinned end.
B. Cap and lining (brass).
C. Bend with screw for iron.

Fig. 124.



A. Tinned end.
B. Cap with thread for brass.
C. Union „ „ iron.

Fig. 125.

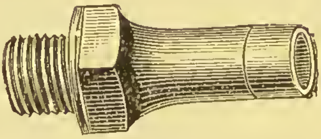


Fig. 126.

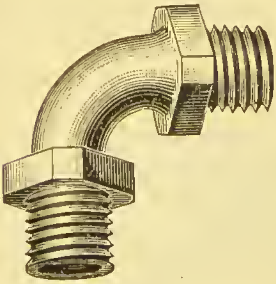


Fig. 127.

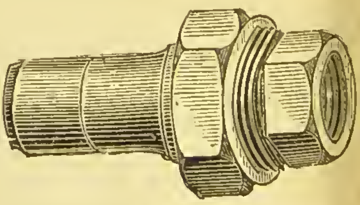


Fig. 128.

or cock with coned joints at either side connecting it with the service pipes.

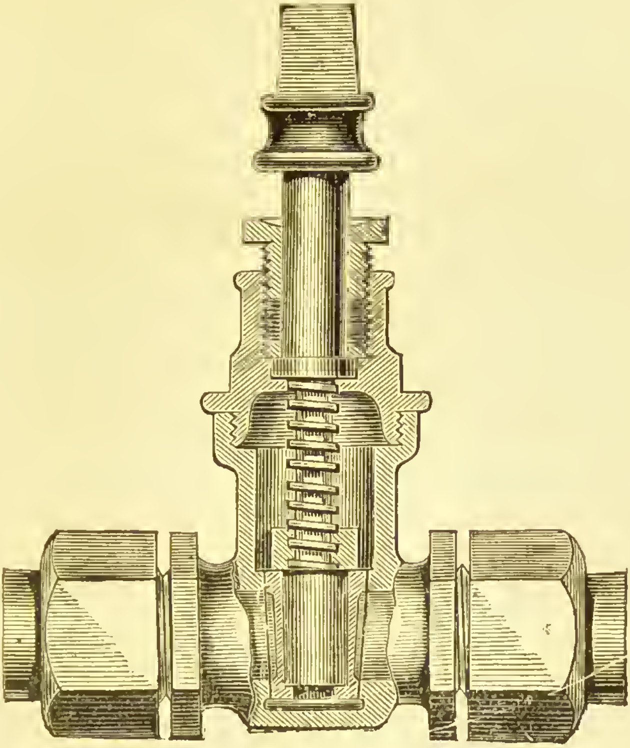


Fig. 129.

The objection to lead pipes is that they are more liable than iron pipes to permanent damage from the great shocks owing to the sudden closing of plug taps, but the introduction of screw-down valves has to a great extent obviated this. The following remarkable results are given by Mr. Binnie. A lead pipe ¾-inch in diameter and 114 feet long was attached at one end to a 3-inch supply main, and at the other was fixed a plug-cock with an effective water-way of 0·152 inch. The pressure of the water was observed in the lead pipe by a gauge fixed near the top, when it registered as follows :—

Before opening	125lbs.	per square inch,
When opened	20 ,,	,,
When shut quickly	550 ,,	,,

which was reduced after numerous vibrations to 125lbs. per square inch.

The pressure gauge was then removed to the inlet of the lead pipe, 114 feet from the tap. The result was :—

Before opening	125lbs.	per square inch.
When opened	120	,, ,,
When shut quickly	220	,, ,,

The result of this continued hammering causes a swelling out of some weak part of the pipe, and ultimately a fracture.

The result of these experiments indicates the danger of shutting off a tap suddenly. The action will affect not only the pipe where the water is cut off, but also places connected with the same system. The result of the vibration will be communicated to all cisterns or equilibrium valves in the vicinity, causing an injurious effect upon the working parts. This points to the necessity of careful closing not only as regards the valves themselves, but on the part of taps and all other fittings in connection with a water system under pressure.

To revert once more to the question of lead pipes; another objection made to both lead and galvanized iron is that these metals have a deleterious effect, especially lead, upon the quality of some drinking waters. Moorland waters especially have the reputation of acting upon lead so as to render the water unsuitable for drinking, and in order to prevent this injurious effect the "Health Water Pipe" has been introduced, and has obtained the highest award at the British Medical Association's Exhibition. This pipe is of wrought iron, lined with pure white metal. The makers are Messrs. Walker & Co., Heckmondwike.

Position of Service Pipes in Buildings.

Above ground, cold-water pipes should be secured to walls or timber with brackets or hooks. If exposed in passages, etc., they should be covered with non-conducting felt, or other material, and enclosed in a deal casing. As far as possible, service pipes should be kept on inside walls at a distance from windows or ventilating openings. They should be fixed *in such a position as to be easy of access*, vertical pipes, as a rule, being carried up in the angles of walls, and if any pipes are placed in plastered walls they should be cased in with wood casings fastened with screws, so that under any circumstances they can be easily taken down.

At some point on the line of service pipe, immediately before or after it enters the house, a stop-cock should be placed to allow the water being shut off from the house. It is advisable to have it placed in a surface box outside, so as to admit of inspection. This subject will be more fully considered when we discuss the question of waste detection.

Another precaution, to prevent discomfort in frost, should never be omitted in any house. A tap, commonly called a "draw off," should be fitted to the service pipe just before it begins to ascend, so that if the stop-cock leading to the main be closed, the house supply pipes can, through this tap, be emptied. During a hard frost this should be done every night, for it is then that all the mischief is done by pipes full of quiescent water congealing. In barracks the draw-off tap may be placed in the same pit as the stop-cock, outside the house. The barrack turn-cock, when going his rounds at night, can shut the one and open the other, reversing the operation in the morning. The water thus allowed to run to waste will be very little; it may either be connected with a drain, or allowed to soak into the soil. In the quarters of senior officers the draw-off tap may be inside the house, but in other military buildings it is better to have it outside close to the stop-cock.

If the house pipe, after leaving the ground, is exposed even against an outside wall, though inside the house, it should be lagged with some non-conducting material, such as felt, paper, silicate cotton, etc. Wrought-iron pipes are more liable to be burst during a frost than lead, owing to the greater ductility of the latter.

Considering how vitally important to the comfort and health of the occupants of a house the water supply system is, it is surprising how carelessly pipes are arranged, as a rule, in England, and how apathetic householders are with regard to the subject, until an unusually severe winter, like that of 1895, gives them a rude awakening.

The broad principles of construction are simple. The pipes should be :—(1). Everywhere accessible. (2). Capable of being emptied. (3). Surrounded by non-conducting materials where exposed. (4). Under control by taps or stop-cocks throughout.

METERS.

These are *necessary* on distribution pipes, where water is paid for by consumers, and *advisable* at certain points on supply mains to check leakage and consumption.

There are a great variety of meters, but they can be generally divided into two classes: (1), those which measure directly the quantity of water passing through; and (2) those in which the quantity is inferred from the movement of a revolving disc, or from the action of other apparatus set in motion by the passage of the water. These two classes, therefore, may be called *direct-action* or *positive* and *inferential* meters. Of direct-action meters, one of the best known is Kennedy's patent, constructed by the Glenfield Company, and illustrated on *Plate* XLVII. In this case the quantity of water that fills a cylinder of known size is the method on which the apparatus works. In the cylinder there is a piston, with a rod at the upper end terminating in a rack and pinion. This rack is attached to a weighted lever, which falls over by its own weight when the rack has been raised by the action of the piston beyond a certain height. The water enters in through a 4-way cock between C and D, and is directed either above or below the piston (in the plate it is directed below the piston), the pressure of the water causing the piston to fall or rise, and, therefore, actuating the rack and weighted lever above, the water being expelled in the direction of the arrow by the outlet B. When the weighted lever falls over, it reverses the motion of the 4-way cock, and causes the water to flow below the piston where formerly it had entered above it, and thus to reverse the motion of the rack, somewhat in the same way as a slide valve reverses the entrance of steam into the cylinder of an ordinary steam engine. The number of single strokes, multiplied by the capacity of the cylinder, minus the clearance and cubic contents of the piston, gives the consumption of the water in any given time, and is communicated through a system of wheels to a dial face.

The Schönheyder meter (Beck & Co., London), is also a direct action meter where there are three cylinders (*Fig.* 2, *Plate* XLVIII.), of a known size round a central axis, the water entering each alternately. *Fig.* 11 on the same plate shows the three pistons which rise and fall in these cylinders, and which are connected by a cup-shaped valve cover, which slides over the parts shown at the top of *Fig.* 2. *Fig.* 9 shows the apparatus complete.* Other English meters, not illustrated here, are the Parkinson, Frost and Kent meters.

Of American manufacture, the "Crown" meter, the "Bee" meter, and the Hersey meter are shown on *Plate* XLIX. These are all largely used, and have the merit of compactness.

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* These figures are from blocks kindly supplied by Messrs. Beck & Co.

Small meters, applicable to the measurement of house consumption, have received much attention in America.

Of *inferential meters*, one which is much used is Siemens' patent, constructed by Messrs. Guest & Chrimes, of Rotherham. This meter acts on the principle of the turbine wheel, by the revolutions of which, due to the flow of water, we infer that a certain quantity has passed through the meter. The cast-iron case which forms the body of the meter is divided into an upper and lower chamber, as will be seen from the drawing (*Fig.* 130). The water enters through strainers at B, descends through the meshes at C by the channel D, and passes in the direction of the arrows through E and F. The spindle is actuated by means of an endless screw; the wheel which works it

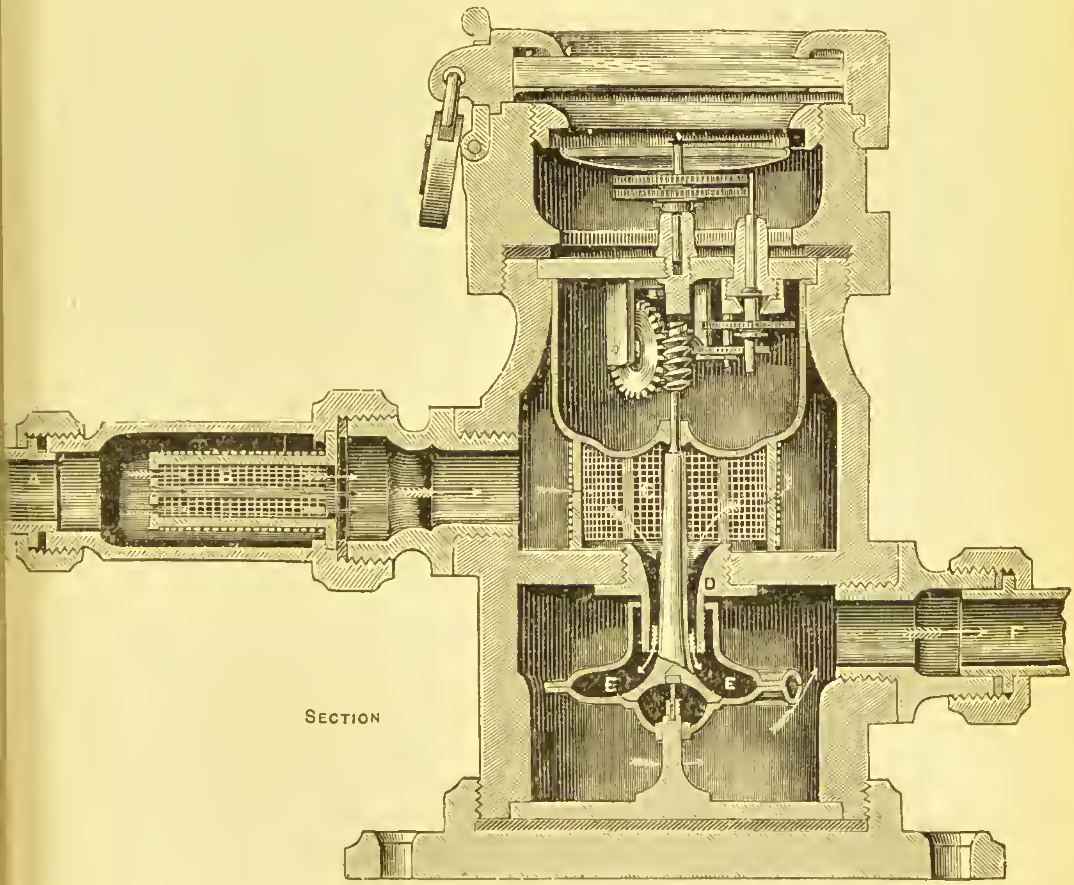

Fig. 130.

is situated at the upper part of the instrument. A simple revolution of the drum or wheel will not of itself correctly measure the quantity of water, because the velocity would vary with the pressure. This is compensated by vanes attached to it, which are so formed as to offer a resistance which increases as the square of the velocity. By this means the balance of power is obtained; consequently the number of revolutions is constant under varying pressures for smaller quantities of water passing through.

The drawback to this form of meter is that it requires to be returned to the manufacturer for repairs, and the delicacy of the working parts is a serious disadvantage where there may be impurities in the water.

Tylor's patent rotary meter is another form of inferential meter very suitable for house use. It is illustrated on *Plate* XLVIII., *Figs.* 1, 3, 4, 5, 6, 7, 8 and 10. *Fig.* 1 shows meter and dirt box. *Fig.* 3 shows the inner case containing working parts, *Fig.* 4 the gearing actuated by the fans in *Fig.* 5, and communicating with dials in *Fig.* 6. *Fig.* 10 shows one of a small size for service pipes.*

In all cases simplicity of working parts is most desirable, and in this respect a meter which has been recently invented in America, called the *Venturi meter*, has much to recommend it. This meter is named after the Italian philosopher Venturi, who was the first to call attention, in the year 1796, to the relation existing between velocities and pressures of fluid when flowing through converging and diverging tubes. It is now being manufactured at the Builders' Iron Foundry, Providence, Rhode Island, U.S.A.

It consists of two parts: a tube through which the water flows, and the recorder which registers the quantity of water as it passes through the tube. The tube is shown in *Fig.* 131, and, as will there be seen, takes the shape of two truncated cones, joined by a short throat-piece at T.

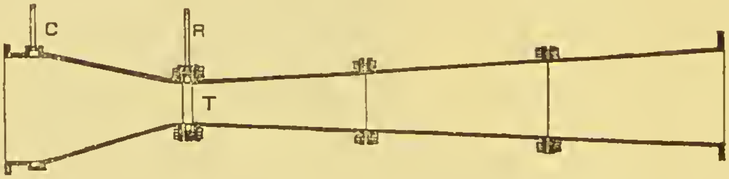

Fig. 131.

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* These figures are from blocks kindly supplied by Messrs. J. Tylor & Sons.

At the up-stream end and at the throat there are air chambers C and R, at which points the pressures are taken. The action of the tube is as follows :—

Supposing the pipe to be conveying liquid from C towards T, the velocity of the flow through the waist will be greater than in the normal portion of the pipe. Hence, the velocity of the flow being greater, the pressure must be diminished because no work is done by the liquid as it flows through that portion of the pipe, and the energy of the water will be the same in all portions of the conduit. The energy depends upon three terms : the gravity head, the pressure head, and the velocity head. In a level pipe the gravity head will not change from one end of the pipe to the other, and, therefore, the sum of the pressure and the velocity heads must be constant, leaving friction out of consideration for the present. The difference of pressure, therefore, exerted at the waist and at the up-stream end will be a function of the velocity and of the hydrostatic pressure which would obtain if the water were motionless within the pipe. The difference of pressure or head at the entrance and at the throat of the meter is balanced in a recorder connected with the tubes, and placed in any convenient position within 1,000 feet of the tube.

In the recorder there are two columns of mercury in cylindrical reservoirs, one within the other, the inner carrying a float, the position of which indicates the quantity of water flowing through the tube. Now no pipe can be made absolutely frictionless, hence the theoretical velocity obtained by any such system as this has to be multiplied by a constant, determined by experiment. By means of this extremely clever invention, accuracy may be obtained in conjunction with great simplicity. It may be used as a waste-water meter, keeping a record of the quantity passing through the meter at any time.

In addition to the Venturi meter, there are a number of other inferential meters constructed by various firms, such as Tylor's patent waste-detecting meter, Siemens & Halske's patent meter, and various others. For the detection of waste of water, Deacon's meter is well adapted, and is very ingenious. The description of this meter, however, is deferred to a later chapter, when the subject of water detection is considered.

It is not here possible to state which of these various meters is the best, and it would perhaps be unfair and invidious to do so. The broad principles, however, on which a meter should be selected for barrack purposes are that it should be simple, not liable to derangement in any of the working parts, and applicable to the different sizes of pipes.

The addresses of firms supplying the meters are given in the manufacturers' list at the beginning of this book, and further information can be obtained on application to them; but it would not be possible in the limits of this work to give a detailed description of all. Moreover, in English barracks, the supplies are generally governed by meters provided by the local water company, whose duty is also to keep them in repair. The R.E. have nothing to say to the pattern thus supplied, although, of course, they can claim to have the meter tested.

In arranging meters in a barrack, it is desirable to have some such arrangement as shown on *Plate* L., which is the system recently adopted at Aldershot. The system is double, so as to admit of removal for repairs, and dirt boxes are given to collect solid impurities which might injure the working parts. *Fig.* 132 shows a section of a pit with dirt box and meter.

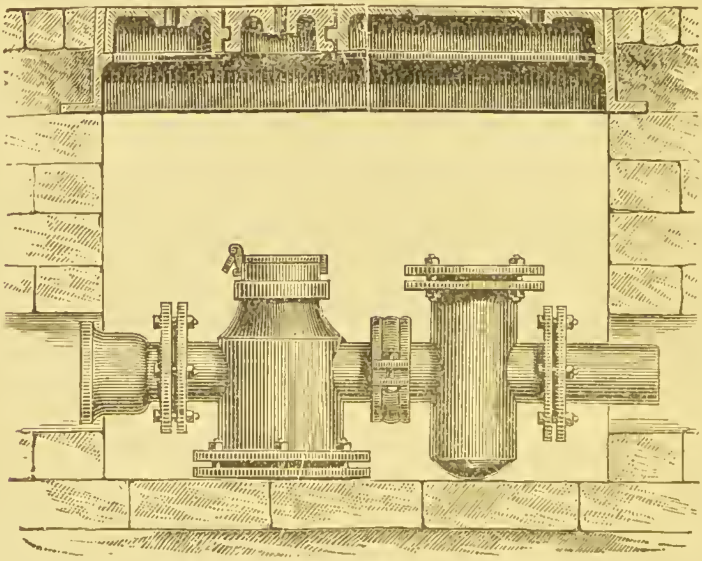

Fig. 132.

CISTERNS.

Under the continuous system (to be described in a later chapter) cisterns for houses should be confined to the smallest sizes required for use with hot-water apparatus, w.c.'s, etc. With the intermittent system, storage cisterns will be required. Those that hold more than 300 gallons should be made of cast-iron plates with flanges bolted together and the joints filled in with rust cement; under 300 gallons the cisterns may be made of slate, but there are many objections to them, viz., their great weight, cost, and liability to leak, especially in frost. Storage cisterns under 300 gallons are generally made of galvanized iron, but the usual custom of leaving them uncovered is much to be condemned. As will be seen subsequently, when considering the subject of intermittent as against constant supply, storage cisterns are most unsanitary under any circumstances, and especially so when uncovered. Cisterns are generally placed "somewhere in the roof," the access to them being by a trap door through a ceiling, and the surroundings being such that one cannot by any possibility examine them in comfort, or indeed examine them at all. Not unfrequently they are so large and in such a confined situation that to take them out for repair or cleaning would involve pulling down part of the house.

In frosty weather such cisterns are a source of great discomfort. They are placed in most favourable positions for the attack of frost, and sometimes for the flooding of the entire household.

The officer commanding troops in a barracks is responsible that the cisterns are "at all times kept clean and sweet" (E.S.R., para. 822), a responsibility which, however excellent in theory, is practically null and void in many cases, where cisterns cannot be examined.

The Barrack Synopsis lays down that cisterns should be supplied to various quarters in barracks, the sizes varying with the nature of the quarters. We have, therefore, to consider what would be the best type of cistern to use under such circumstances. In order to minimize the evil, it is desirable that the whole of the top should be covered, leaving a small portion hinged at one end immediately over the ball-cock, for the full width of the cistern. Thus that portion of the cistern may be opened, and the valve examined or the cistern cleaned.

It is extremely desirable that in every place where a cistern is required easy access should be given, and ample light should be admitted. They should be protected from frost by a casing of deal, as shown in drawing (*Plate* LI.), lined with a layer of silicate of cotton. The outlet of the cistern shown on *Plate* LI. is on the side, and is not visible in the drawing. There is a mud outlet at the bottom, furnished by a plug and washer attached to a chain. Storage cisterns should also have safes of deal lined with lead, with a waste pipe carried directly into the open air.

For connecting the cistern with feed and discharge pipes, brass screw union joints should be used with double nuts. This admits of the cistern being removed without any trouble when desired.

It must not be inferred from the foregoing that storage cisterns are recommended for use; on the contrary, it is to be hoped that before long their use in barracks will be entirely discontinued.

In all well-regulated cases the water for domestic purposes should be drawn *direct from the service pipes*, and not from a cistern, and certainly not from a cistern which also supplies the water-closet. The whole of the supply to w.c.'s requires to be guarded and protected in every possible manner, on the one hand to prevent undue waste, and on the other hand to keep them perfectly healthy and clean. This subject is beyond the scope of this work. It is here sufficient to say that water-waste-preventing cisterns should be universally used, allowing a flush of not less than 2½ gallons of water each time. They should be provided with large down-pipes without bends, to deliver the flush with great rapidity, and as all ball valves are apt to get out of order, a waste or warning pipe should be provided.

BALL COCKS.

Ball cocks or *equilibrium valves* are used to control the amount of water flowing into a cistern. A floating ball of copper is attached (in the old-fashioned patterns by brazing, which was a flimsy attachment, and has been superseded in newer patterns by being screwed into a boss on the side of the ball) to a lever arm in such a manner that when the surface of the water is lowered it carries with it the ball, which actuates the lever arm, opens the valve, and allows water to flow in (see *Figs.* 133 and 135).

These ball cocks are made for use in cisterns, but the same principle can be applied for use in large tanks (see *Fig.* 71, page 146).

The action of the opening valve varies in different patterns. That shown in *Fig.* 133 is metal-faced, acting vertically. Others, such as Doulton's patent, have a horizontal action with metal faces. Those with metal facings, however, are more liable to get out of order than patterns faced with cup leathers and washers.

The cup leathers are of leather dressed in oil, and the material for the washers may be either:—(1). Leather, which has the disadvantage of becoming hard. (2). Vulcanized indiarubber, which, if thick, cracks and tears under high pressure. (3). Alternate layers of indiarubber and canvas, which is in common use now,

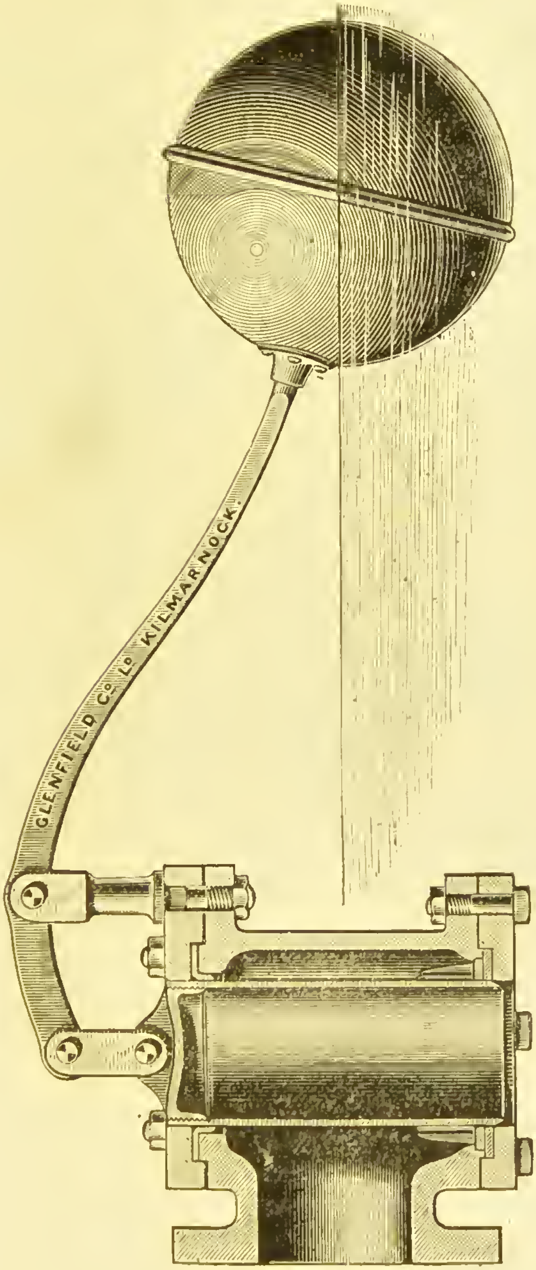

Fig. 133.

does not crack or tear, and gives general satisfaction. (4). Vulcanite, which is expensive, but is used for hot-water pressure.

A very good form of ball cock, among the many patents which exist, is that shown on *Fig.* 136, with a straight lever arm and a counter-weight. By means of the screw A the length of the lever arm may be altered, and then if the valve does not act properly the leverage may be easily altered.

In other cases this alteration is effected by bending the lever arm. If done at all this should be done with two pairs of strong pliers. Trying to do it with the hand generally breaks the lever.

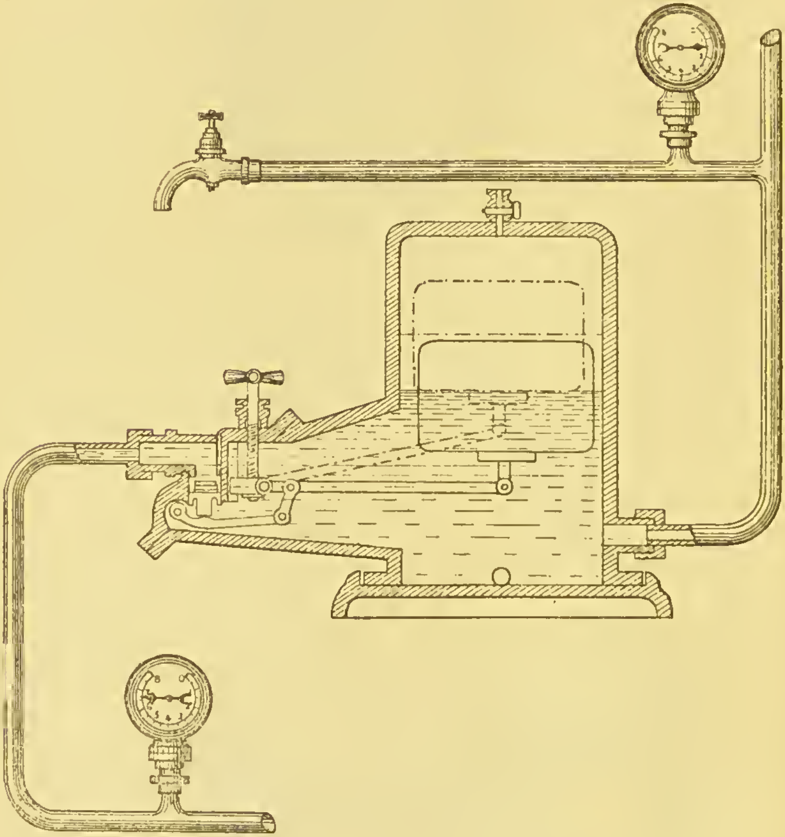

Fig. 134.

A form of domestic break-pressure tank is shown in *Fig.* 134, which is partly section, partly plan. The adjustable lever actuated by a screw handle is the chief feature in this invention (patented by Herr Proett, of Rhydt), which received a silver medal at the Antwerp Exhibition of 1893. Presumably it would be used with a high-pressure constant supply, and be fixed on a bracket at the highest part of the building to be supplied, in some readily accessible position.

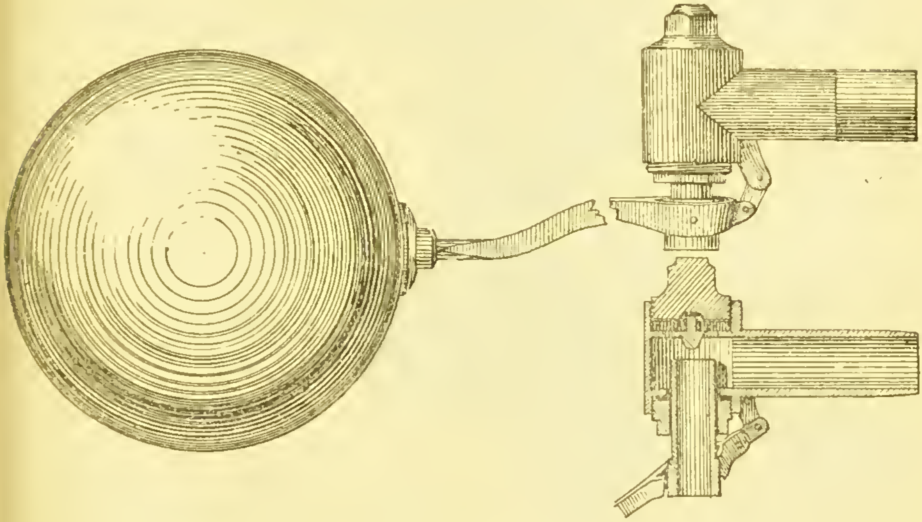

Fig. 135.

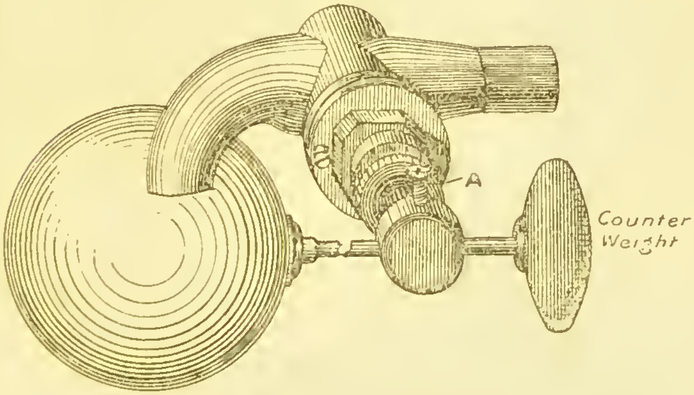

Fig. 136.

BIB VALVES OR TAPS.

A proper provision of taps in domestic supply is of great importance in connection with the prevention of waste.

The requirements for a tap are as follows :—

1. It should be simple in its action.
2. It should have no complicated working parts.
3. It should be repairable without cutting off the water in a pipe,

Taps are all variations of three kinds:—(1). Plug taps. (2). Push taps. (3). Screw-down taps. *Fig.* 137 is the old-fashioned ground plug tap, the action of which is very simple, but it is a source of an enormous waste owing to leakage, and it causes injurious strains upon the pipes, as has been noticed already, owing to the sudden closing. However well fitted this tap may have been in the first instance, a very little grit coming between the seating and the plug will wear away the metal, and will certainly cause the tap to drip. This form of tap, therefore, should not be used in barracks, or, indeed, anywhere else. If used anywhere, the weight and pressure which it is required to stand should be specified.

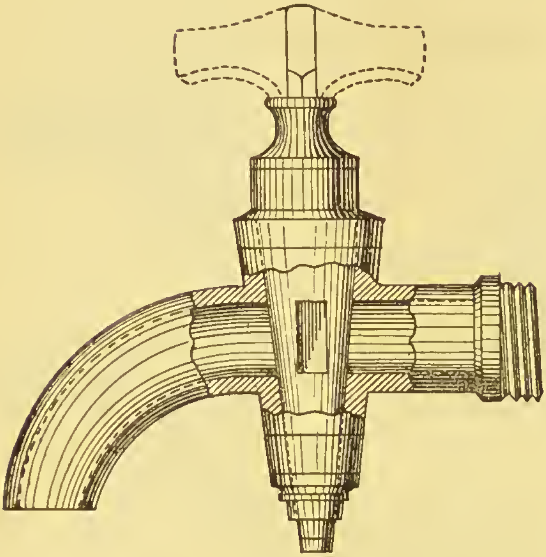

Fig. 137.

Push or spring taps (*Fig.* 138) are often used in lavatories and smaller places, and have been adopted in some cases in barracks. They are, however, not to be recommended for general use, as they are very liable to get out of order, expensive to repair, and a fruitful source of waste of water when out of repair. They are open to the same objection as plug-taps, with regard to sudden check. For use in India, some officers consider them good, as the automatic closing prevents a certain amount of waste.

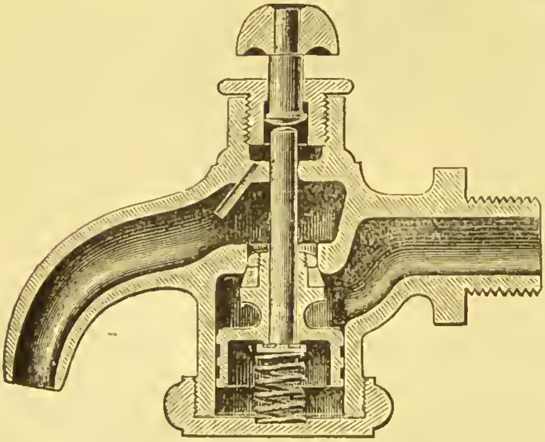

Fig. 138.

The screw-down tap (*Figs.* 139 and 140), made of strong brass, is a suitable form for general use. It is a loose valve which, as will be seen in *Fig.* 139, is drawn up when the screw is raised, and allows the water to flow. When the screw is turned down, as there is no connection between the screw and the valve, the latter is not worn by the constant friction on the seat, and water-tightness is insured by a little leather diaphragm. There are two ways whereby a tap can be constructed so as to be repairable when under pressure. The first method, illustrated in *Fig.* 140, showing a tap constructed by Messrs. Guest & Chrimes, is to have two diaphragms, above and below the aperture, independent of each other. The upper one usually does the work. When the leather becomes worn the upper part is screwed off, and the water pressure, acting underneath the lower diaphragm, closes the orifice so that repairs can be carried out without cutting off the water from the tap.

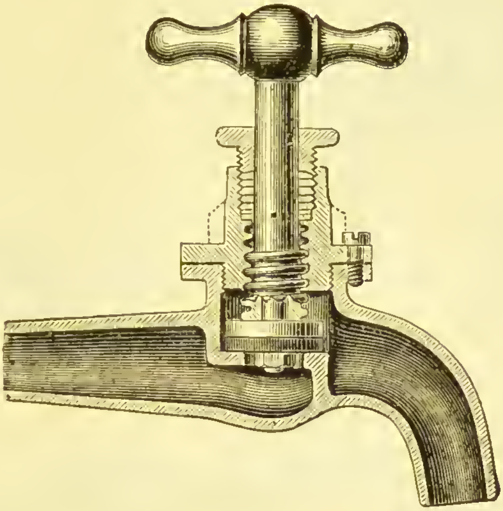

Fig. 139.

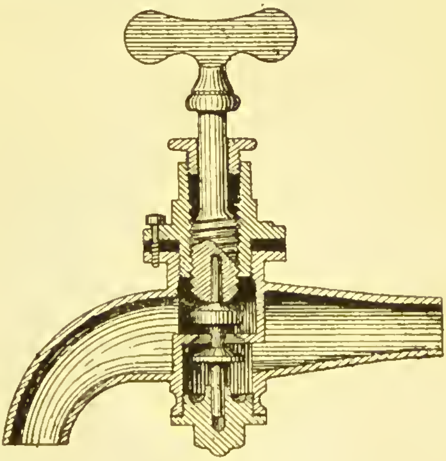

Fig. 140.

Another form of repairable tap is illustrated by Hams' patent, manufactured by Messrs. J. Stone & Co. (*Figs.* 141 and 142). It will be seen that here there is a slot A cut in the thread of the

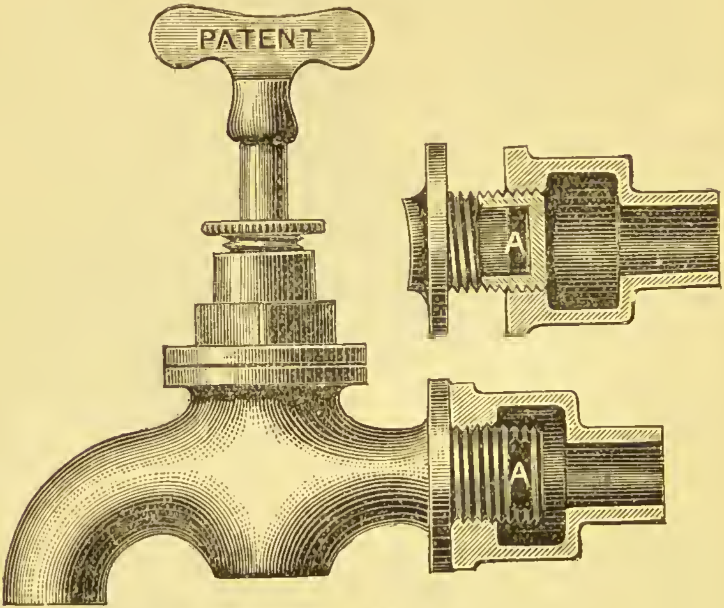

Fig. 141.

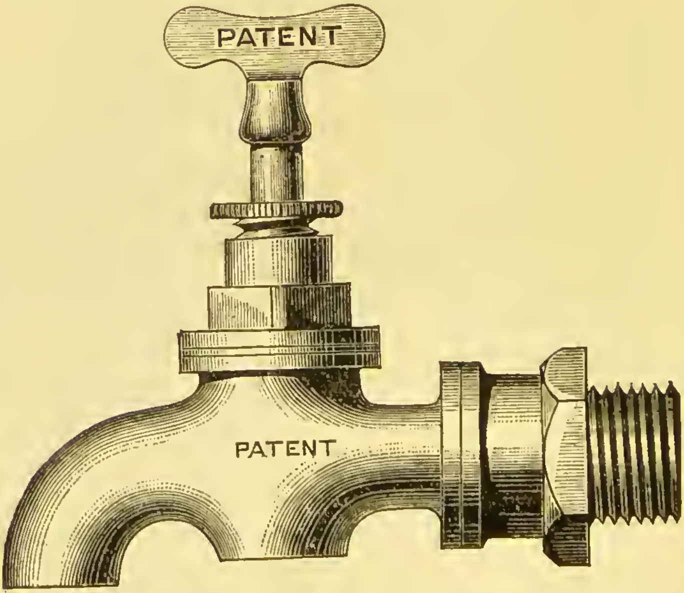

Fig. 142.

screw, through which the water passes to the tap. When repairs are required, about six turns of the tap will bring this slot to the position shown in *Fig.* 141, and will thus prevent any water passing through. The repairs can then be carried out, and when finished the tap can be screwed back to its former position. If used with a lead pipe this tap can be screwed to a brass bracket, as shown in *Fig.* 143.

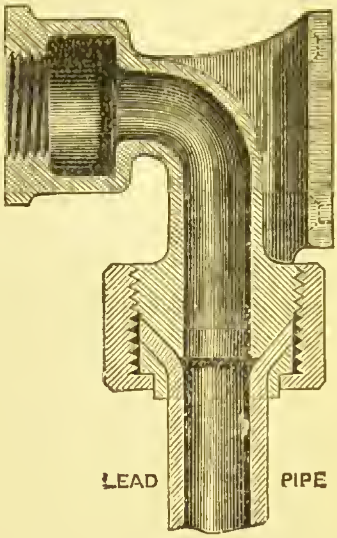

Fig. 143.

Lord Kelvin's tap is shown in *Fig.* 144,* and the peculiar advantages of it are:—(1). It has no fibrous or leather washer. The washer A is metallic. It is held in the case B by two projections, which are confined by the slots CC, leaving the washer free to revolve within certain limits. At every operation of opening or closing the washer is rubbed upon its seat, and as it does not always occupy the same

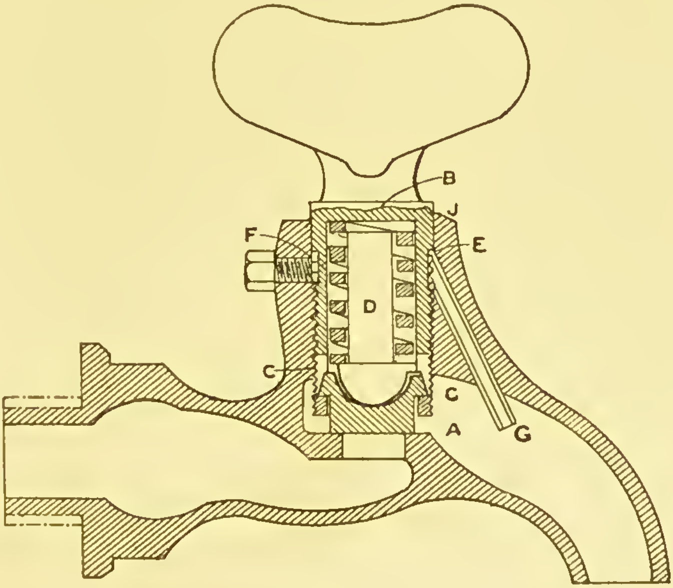

Fig. 144.

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* *Minutes of Proceedings of the Institution of Civil Engineers*, Vol. CX, p. 272.

position, is not worn unequally. (2). It does not drip. The water in passing out induces a current down the tube G, which carries away any trifling leakage. At F is an annular groove communicating with G, so that no water leaks between the can B and the body of the tap at J.

D is a rivet-shaped piece of metal, which presses on the washer A, and is kept in position by the screw E.

Of course this tap is not repairable in the sense that those shown on *Figs.* 140 to 142 are, but its mechanism is contrived so that repairs may not be necessary.

CHAPTER X.

MISCELLANEOUS STRUCTURES AND FITTINGS.

Watering of Animals.—Rain-Water Tanks.—Fire Protection.—Fittings.—Other Miscellaneous Apparatus.

In all barracks and cantonments provision has to be made for the watering of horses and other animals. In England it is customary to have water troughs situated between the lines of troop stables. These troughs are supplied from a branch taken from the main and governed by a ball-cock, which is usually situated under a locked cover so that it may not be interfered with. The troop horses are taken out to water three times a day, before morning, mid-day, and evening stables.

This system has several disadvantages :—(1). It is objectionable in frosty weather. (2). It is a cause of accidents. (3). Horses are hurried in drinking.

(1). In time of frost the troughs are frozen, and the horses have to be watered by buckets filled from the nearest cook-house. In a long frost this becomes excessively inconvenient where a large number of horses have to be supplied.

(2). It is not possible to keep the surroundings of the troughs so free from water spilling that in frosty weather there should be no liability for the horses to fall and injure themselves. Accidents frequently occur from horses falling when being led out to water, even though sand and gravel is sprinkled round the troughs.

(3). It is an axiom in all stable management that horses should not be hurried when drinking, and that they should be watered before they are fed. By having the troughs outside it is inevitable that a certain amount of hurry must take place. It is impossible to expect that the men who take the horses out to water shall not become impatient, especially in the morning and evening, and thus it frequently happens that the horse is taken in before he has had his proper drink. Again, the object of watering horses before they feed is to prevent any possibility of undigested grains being washed into the intestines, but there is no reason why a horse should not drink if he has access to water during his feed. From the foregoing remarks it will be understood that a great advantage would accrue if the water could be brought to the horse in his stable instead of his being taken out of his stable to the water. This subject has been treated in a lecture on "Stable Management," delivered at the R.A. Institution by Veterinary-Lieut.-Colonel Walters, C.B., and in the discussion which followed it was thoroughly agreed among artillery officers of experience that it would be best to bring water into the stable, and thus enable the horse to drink at any time. Such an arrangement would not be difficult to carry out, and might be contrived so as to be independent of fluctuations of the weather. A combined manger, hay rack, and water trough is in use in some private establishments, but has not yet been introduced into barracks. These articles are constructed by the St. Pancras Ironworks Co., by the Carron Co., Falkirk, N.B., and many other firms. The water to supply this apparatus can be brought through pipes along the stable wall, and the supply to the whole of the stable can be governed by a cistern with a ball-cock. In frosty weather the supply can be cut off, and the whole of the pipes emptied by means of a waste tap. It would appear that some such arrangement as this would be better than the present method of watering horses in troughs outside. For horses, lake or river water is better than well water.

As regards the amount drunk by horses, experiments were carried out at Aldershot in the winter of 1891–92 to ascertain the average amount drunk by the horses in a squadron of cavalry.* The average quantity proved to be 5 gallons, but it must be remembered that this was the cold weather amount, and that in summer, when the horses are doing hard work, the amount consumed would probably be 6 or 7 gallons. An allowance of 8 gallons per horse is, therefore, necessary for drinking alone, and 2 gallons more should be allowed for the cleaning of harness and wagons in connection with mounted branches.

It is of great importance that where troughs are used the water should be subjected to a cleansing process, so as to prevent the scum accumulating on the surface. The water overflowing from one trough should not be allowed to flow into the next. Muirhead's patent automatic water-supply and flushing valve for horse and cattle troughs, as manufactured by the Glenfield Company, is shown on *Plate* LII. When the level of the water is lowered by drinking, a float C sinks and opens a small valve, allowing the water to flow through the tube E into the float F. This float consequently sinks and opens a large ball-cock G, which allows the water to enter at the bottom of the trough, and the water in the float F is meanwhile gradually escaping into the waste pipe J. Thus noxious matter from the surface is carried off quickly, and is replaced by clean water from below. Impure water is a great source of danger to animals, and various diseases have been spread by a healthy animal drinking from the water trough in which the scum left by a diseased animal has not been effectually flushed away. In Glasgow all the water troughs have been fitted with Muirhead's apparatus. A considerable saving of water has been effected, and no doubt there has been little spread of infectious disease from the drinking troughs. In any case, whether this Muirhead's apparatus has been adopted or not, it is very desirable that the water entering a cattle trough should come in at the bottom and not at the top. The impure matter on the surface may be removed by causing the overflow at one end to be over the whole width of the trough. This may be further facilitated by slightly inclining the entire trough towards the overflow end. An important point in connection with water troughs is the means for thoroughly cleaning them. It is considered that where they are much used, as in large cities, they should be cleaned every two days. This can be very simply done by constructing the floor of the trough with a gentle inclination towards the centre, where a mud-cock or tap should be provided to empty the entire contents. The result will be that the water itself will cleanse all impurities resting on the bottom of the trough. *Fig.* 145 shows a cattle trough of a very

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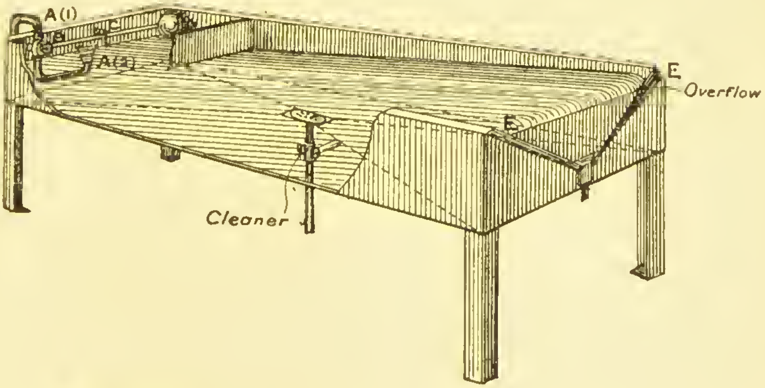
* Of the 5th Dragoon Guards. The meter used was a Siemens. Meter readings were taken daily and registered on a board, on which were also entered the total number of horses watered.



A_1 Inlet pipe.
A_2. Do. orifice turned upwards.
B. Valve.
C. Ball cock.
E. Overflow over whole width, with pipe converging to centre.

Fig. 145.

simple description introduced by Brigade-Surgeon Pringle, M.D., which illustrates the various principles we have mentioned above. This was granted a silver medal at the Health Exhibition of 1894.

UTILIZATION OF RAIN WATER.

Although pure rain water is not considered very palatable for drinking, yet it is useful for many other purposes, especially for washing, and, therefore, in many cases, it is very desirable to collect the flow from roofs and other surfaces* in order to supplement the supply from a well or river or other source. In many places (*e.g.*, Bermuda and other coraline islands) the main supply is dependent on the collection of the rain on prepared surfaces, and its subsequent storage.

At many of our Indian hill stations it is very important that the rain water falling on the roofs should thus be utilized, because frequently the whole water supply for the cantonment is obtained from springs at some distance down the hill-side, and carried on the backs of men or animals to the buildings above. To say nothing of the labour this involves, there is no doubt that considerable danger exists of contamination of the spring, owing to the fact that it lies below the buildings which it supplies. Hence every attention should be paid to the collection and purification of the rain water which falls in slightly varying quantities every year on the roofs of the barracks.

The character of the water as a drinking water will be much affected by the material of the roof from which it is collected. Roofs of slate and of concrete are in general little liable to any growth or other deleterious substance which will contaminate the water. Accordingly, where slate roofs are used as catchment areas for cisterns, the water from them is likely to be fairly pure. Tiles, especially if glazed, are even preferable to slates; indeed, they are the best possible roofs to be used in connection with cisterns. Metal roofs are somewhat objectionable in that they readily oxidize and give rise to the symptoms mentioned in a former chapter as being due to metallic poisoning. All roofs, however, are liable to fouling from external causes. Soot and ashes accumulate in dry weather, and although it is possible, by introducing the supply pipe near the bottom of the cistern, to ensure the impurities being precipitated on the bottom or else floating at the top, yet they are liable to discolour the water and affect its purity for drinking purposes. Furthermore, animals are apt to pollute the roof, birds build their nests in the gutters and down-pipes, so that an American writer has stated :—"From the point of view of sanitary water supply, cats and pigeons are nuisances, and sparrows a scourge."*

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* If prepared surfaces are used for the collection of water they should be cleaned at all quarterly inspections.

A further source of danger in gutters and down-pipes is found in the depressions caused by the sagging of the gutters. These should always have a decided fall in every part, and should be inspected from time to time so that any substances may be removed. Patent separators, on the principle of diverting the earlier rain water which falls after a drought and allowing it to run to waste while storing the subsequent pure water, are not recommended, as they are liable to get out of order.

Fig. 146 shows an arrangement for storing rain water on a small scale, adopted by the writer at his quarters at Chatham. The water, entering the storage butt by a pipe which reaches nearly to the bottom, impinges against a cone or plate, which prevents it disturbing any sediment which may have settled at the bottom. Any heavy particles settle, lighter ones (such as soot) rise to the top, and there is a gentle overflow by means of a trumpet tube, which fits into the bottom by a turned and bored joint. The water is drawn off near the bottom, and is, to all intents and purposes, perfectly clean, provided it is periodically flushed,

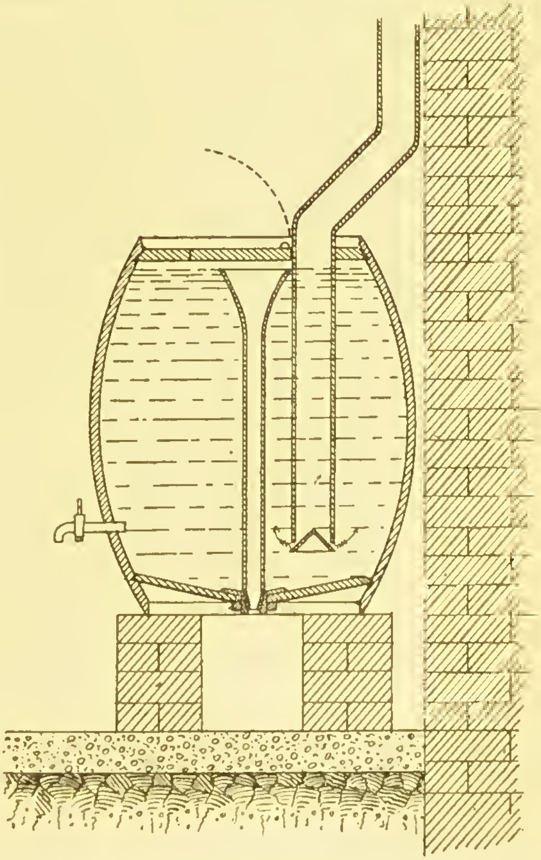

Fig. 146.

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* Geological Survey Report, 1892-3, p. 25.

in spite of the impurities which lodge on the roof. The butt is cleaned by pulling out the trumpet-mouthed tube. There is a slope given on the bottom towards the centre, whereby all sediment is washed out to the mud hole when the tube is withdrawn. This arrangement is on a principle also advocated by Dr. Pringle, and rewarded at the Health Exhibition.

The tank or reservoir for containing rain water should not be, as a rule, directly and permanently connected with the roof; the pipes should be so arranged as readily to be disconnected from the cistern and turned into a waste pipe.

An American form of an underground cistern for containing rain water is shown on *Plate* LIII. (the lower section), the sides being vertical, the floor being slightly arched, and the roof hemispherical or semi-circular. It is possible to exclude surface water by raising the mouth above the ground line. The cover should be of metal, usually cast iron, and the water may be raised by a pump, which passes through an aperture in the cover. The construction of the work will be much the same as the service reservoirs which we have formerly discussed.

Plate LIV. shows a large underground reservoir. The filtration here is upward. But it would be easy to contrive it so that the filtration should be downward. Ventilating pipes should be given to the filters, so as to supply the necessary oxygen for the support of bacteria.

Wooden reservoirs are sometimes used in America, but are not recommended either on economical or sanitary grounds.

The advantages of an underground reservoir are as follows:—

1. The water may be protected from deterioration provided the cistern is carefully constructed of water-tight materials.
2. The water may be kept at a uniform temperature.
3. The supply is fairly certain.

All underground tanks should, however, be provided with a wash-out drain, whereby they can be cleaned. Generally, this can be arranged by conducting the drain to an outfall, but such outfall should never be a sewer, or connected therewith.

PROTECTION OF BUILDINGS FROM FIRE.

An important adjunct in the water supply for a barrack or cantonment is the provision of proper apparatus for the extinction of fires. In every large garrison there is a fire brigade equipped with portable fire engines, pumps, and other apparatus. It is not within the scope of this work to discuss such apparatus, which is, as a rule, not under the charge of the engineers. But it is necessary for the engineer who designs the water supply to arrange for the proper provision and location of the hydrants whence the fire brigade may obtain the necessary supply.

Professor Burton has pointed out that the amount of water required for the extinction of fires may be arrived at from the following approximate formulæ :—

$$Q = 200 \sqrt{P},$$

where Q = minimum quantity of water in cubic feet to be stored for fire extinction, and P = the population. The amount to be provided at each hydrant is 120 gallons per minute (see Chapter VII.). The storage capacity may be either provided in the clean-water reservoir, or in the settling reservoir, or in the impounding reservoir. In either of the two last cases a bye-pass is provided, so that the water for the fire extinction shall not have to pass through the filter beds. Of course, this has the disadvantage of filling the main pipes with unfiltered water, as previously pointed out in Chapter VIII., hence it is best to have the storage capacity provided in clean-water reservoirs. In barracks these should be brought into use at fire practice, so that stagnation may be prevented.

As regards the position of hydrants, they should be so arranged that the whole of the inhabited buildings can be covered by a stream of water from the fire engines, the hose of which is attached to the hydrants. They should not be situated too near the building, as otherwise there will not be room for the fire-engines and firemen to work efficiently. The radius of effective action can be taken at 100 yards, and the position of the hydrants should be at least 20 feet from the building it is intended to supply.

Hydrants may be classified either according to their position with regard to the level of the ground, or with regard to their interior machinery. Following the first method of classification, they will be divided into "pillar" hydrants and "sunk" hydrants. Pillar hydrants are common in many large towns, and have certain definite advantages in that they are conspicuous, are not liable to be buried under snow, and the fire hose can be attached without using a portable standpipe. On the other hand, they interfere with traffic, and for that reason are not commonly used in barracks.

Sunk hydrants are those which are fixed entirely below the surface of the ground; they are contained in a masonry pit closed by a removable iron covering. When they are required to be used, a standpipe, generally of copper, is fixed to the hydrant, and the hose fixed to the standpipe. These standpipes are carried on the ordinary fire engines. In every case the position of a sunk hydrant should be very distinctly marked by a plate on the nearest wall, so that when the ground is covered with snow, etc., there may be no difficulty in finding the position of the hydrant. In some cases luminous paint has been substituted for cast-iron letters to indicate the position of the hydrant.

Messrs. Merryweather & Sons have patented a telescopic hydrant which combines many of the advantages of both pillar and sunk hydrants. When the hydrant is wanted for use, a telescopic tube is drawn up, to which the hose is attached.

Hydrants are otherwise classified as ball hydrants, sluice-valve hydrants, and screw-down hydrants.

Ball hydrants, illustrated in *Fig.* 147, which illustrates a form suitable for small pipes, contain a vulcanite or india-rubber ball which is held up by the pressure of the water against a washer which surrounds an orifice at the base of the vertical pipe. A rod passing down the pipe depresses the ball when it is required to draw off the water, as will be readily understood from the figure. The objection to this form of hydrant is that the balls are liable to lose their shape, and leakage ensues.

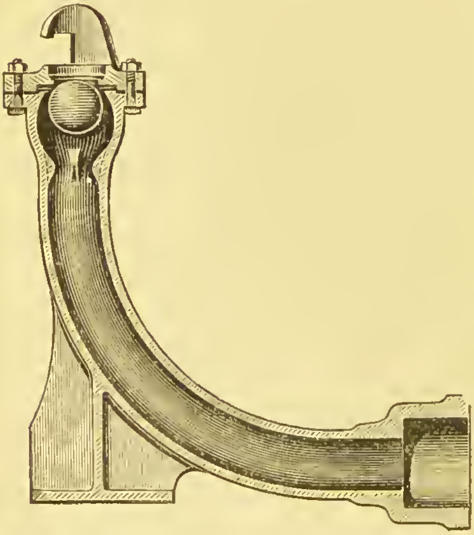
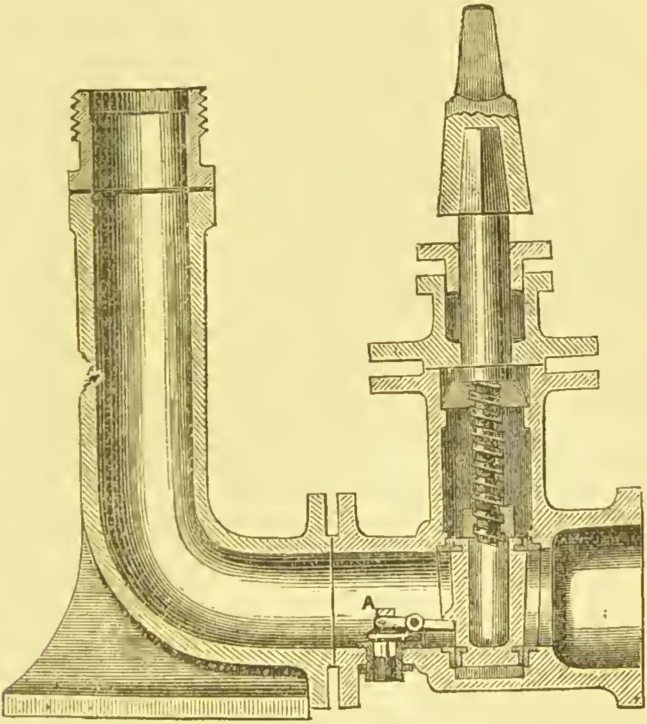


Fig. 147.

Sluice Valve and *Screw-down hydrants* are practically the same, the one having a vertical sluice valve, and the other a horizontal valve working on a prepared seating. The former variety is more usual in England, the latter in America. The sluice-valve pattern is not suitable for use with water that is not filtered, because any grit in the water is liable to cause a wearing away of the parts and consequent leakage. *Fig.* 141

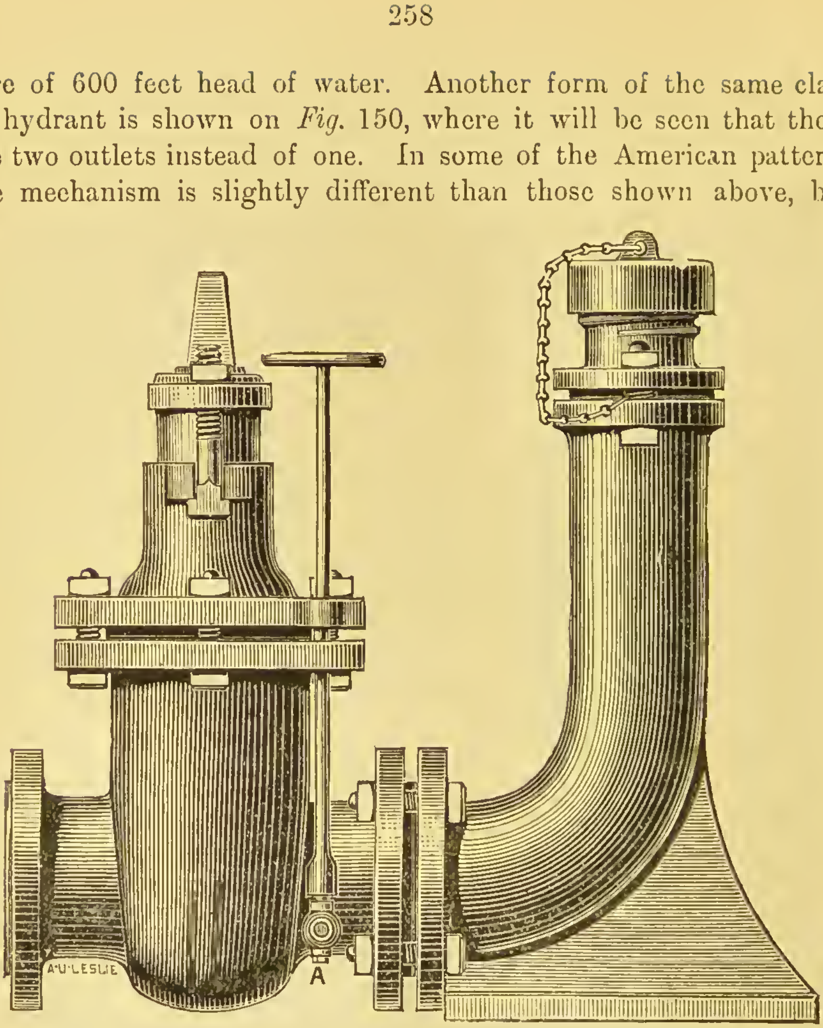
shows the form of hydrant generally used in England. This is fitted with a small *frost valve.* One of the greatest drawbacks to the use of hydrants is the freezing of the water between the valve and the mouth of the hydrant. Obviously, if this occurs, when the hydrant is again required the ice will block the passage of the water. The hydrant shown in *Fig.* 148 has, therefore, a small tap or frost valve near the bottom, which admits of the escape of water between the valve and the mouth of the hydrant. When the sluice valve is opened the small frost valve is shut by the rush of water, and thus



A. Frost valve.

Fig. 148.

the water passes through until the valve is again closed. The water escaping from the small portion of the hydrant flows into the pit in which the hydrant is situated, and causes no inconvenience. Another form of hydrant with frost cock is shown on *Fig.* 149, in which the frost valve is controlled by a spanner from above. This form of valve has been adopted by the London water companies, and the advantages are that it has a clear unobstructed water-way, and the stuffing-box does not require re-packing because it is fitted with cupped leather. Every part of the hydrant is tested to a pressure of 600 feet head of water. Another form of the same class of hydrant is shown on *Fig.* 150, where it will be seen that there are two outlets instead of one. In some of the American patterns the mechanism is slightly different than those shown above, but arrangement is made to have independent valves for each outlet on the outside of each pillar. *Fig.* 151 shows a pillar fire hydrant constructed by the Chapman Valve Manufacturing Company, Boston, which admits of several hose being placed on a pipe at the same time. The mechanism will be sufficiently evident from the figure. *Fig.* 152 shows a similar hydrant constructed by the Ludlow Manufacturing Company, of Troy, New York. This can be made with openings for six hose round the circumference of the pipe. The mechanism of this hydrant is further shown on *Fig.* 153. As regards the size of fire hydrants, the tendency is, at present, to use larger and larger nozzles. Formerly 2½ inches was the usual diameter but they are made now as large as 4 inches in diameter.



A. Frost valve.

Fig. 149.

An important point in connection with fire protection fittings is that the thread of the screw, to which the hose should be attached, should be such as will fit the local fire brigade coupling screws. *Figs.* 1 to 4, *Plate* LV., show the couplings now adopted in the Metropolitan Fire Brigade. This has the advantage of being rapidly attached as well as being little liable to damage.

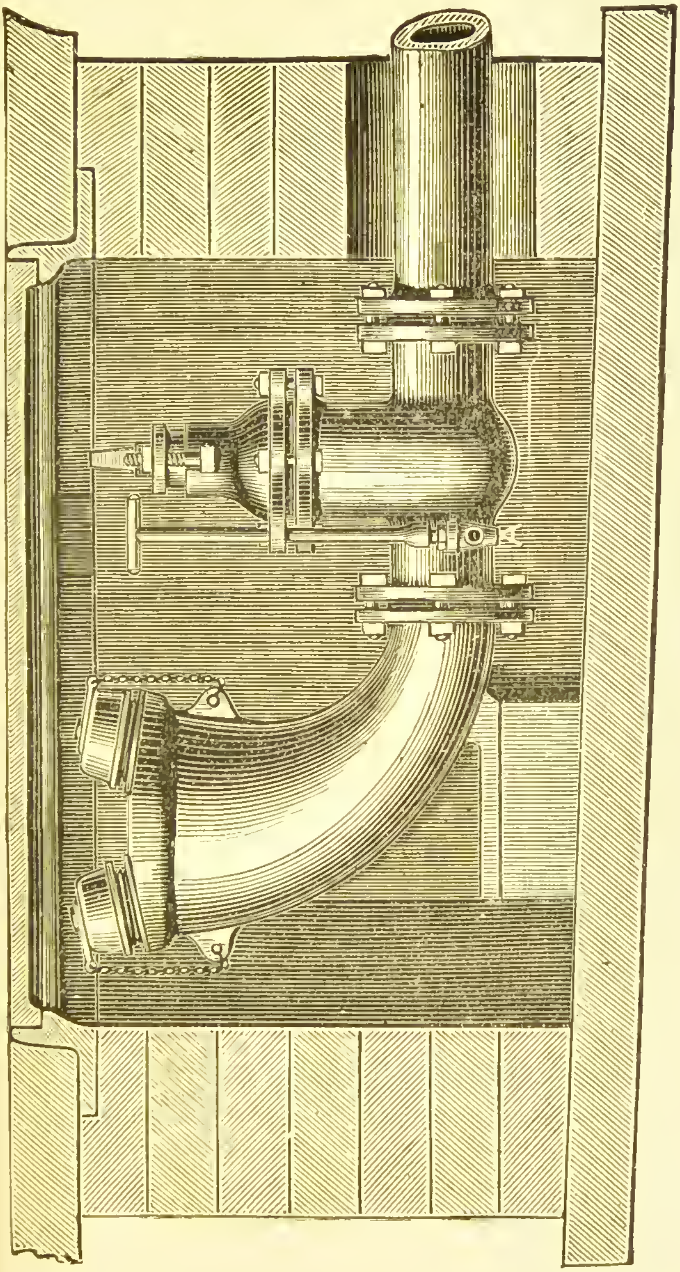


Fig. 150.

A. Frost valve.

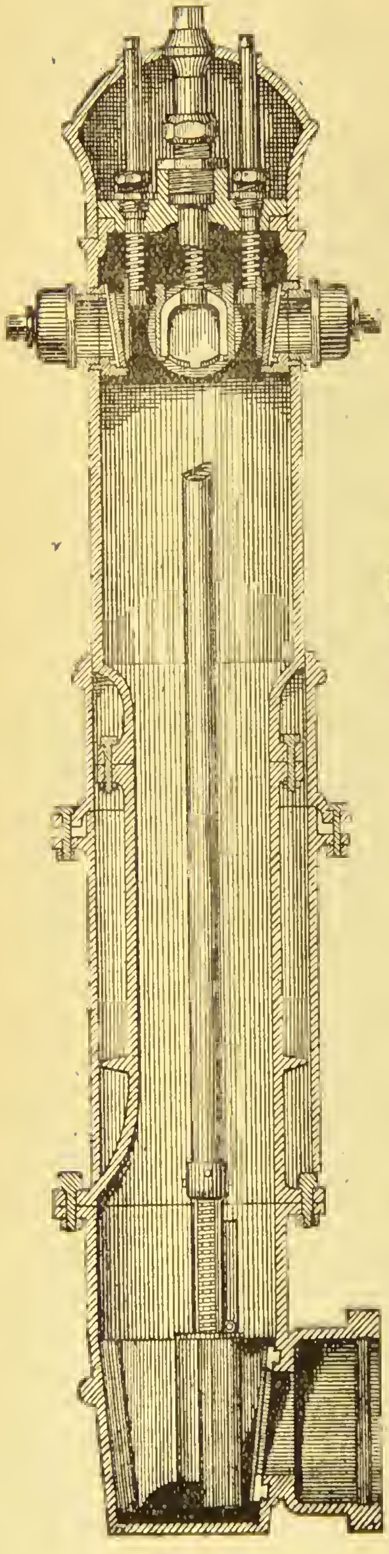


Fig. 151.

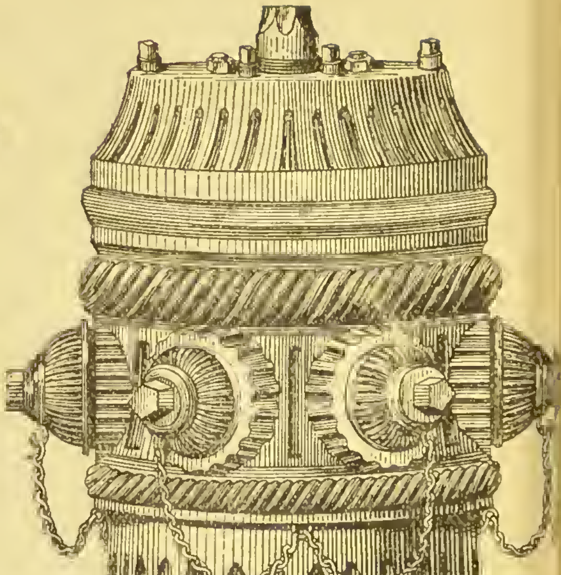


Fig. 152.

Figs. 5 and 6, *Plate* LV., show Messrs. J. Stone & Co.'s patent "instantaneous and interchangeable" hose couplings, the advantages of which are:—(1). Both ends are alike. (2). It has no screw threads. (3). It causes no twist in the hose. (4). Joint is made watertight with a plain square rubber ring. (5). It has no springs, nor anything to get out of order. (6). It is sound under highest pressure. (7). It is cheap.

In large cities where there are hydraulic-power mains along with drinking-water and fire-protection mains, advantage may be taken of the greater velocity of the latter, combined with the superior volume of the former, to produce a much more powerful jet of water in event of fire. The mains are connected at the hydrants by an apparatus something after the pattern of a Giffard's injector (see *Minutes of Proceedings of the Institution of Civil Engineers*, Vol. XCIV., p. 23). By this means a jet of great power can be obtained without the intervention of fire engines.

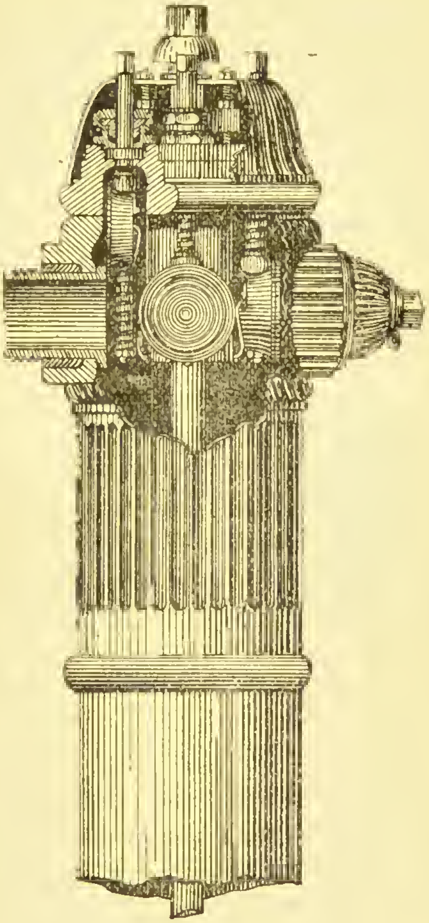


Fig. 153.

Other Miscellaneous Apparatus.

It is only necessary to notice briefly in connection with water service *pillar fountains* for drinking water or for street watering, or, in hot climates, for filling water vessels. In the published catalogues of any of the principal manufacturers will be found a variety of ornamental pillars and fountains suitable for any climate. They are generally fitted with push taps, but these so constantly get out of order that they are not to be recommended. A self-closing tap, with a counterweight, is much better.

Plate LVI. shows arrangements likely to be of use in India, where much of the supply is conveyed to houses from water skins carried by men or bullocks. *Figs.* 1 and 2 on that plate show arrangements for filling skins or jars, and *Fig.* 3 for filling bullock skins. The advantages of such an arrangement, as shown here, will be evident to those who have served in India, and who know how frequently water supplies are polluted by impure vessels being dipped into them. With the arrangements as shown on *Plate* LVI. such pollution is impossible.

Surface boxes are necessary for the protection of stop-cocks, meters, etc. *Figs.* 154 and 155 show section and plan of the "Brighton" pattern of surface box manufactured by Messrs. J. Stone & Co. for covering a stop-cock worked by a key. In this surface box no special tool is required for opening or lifting. The pressure of the foot on the back part of the hinged joint will open it. *Fig.* 156 shows a surface box for meters.

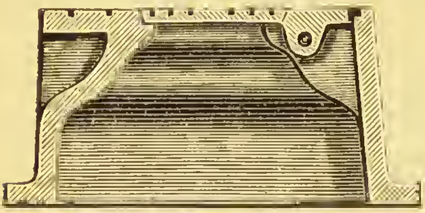


Fig. 154.

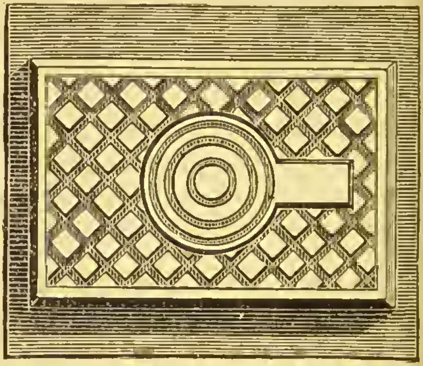


Fig. 155.

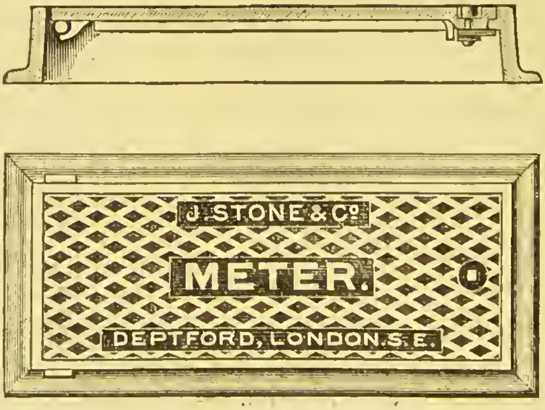


Fig. 156.

CHAPTER XI.

ARRANGEMENTS FOR DISTRIBUTION AND MAINTENANCE.

Systems of Supply.—Detection of Waste.—Distribution Schemes.—Record Plans.—Procedure in Preparation of Projects.—Repairs to Apparatus.

THERE are two systems of supply in connection with waterworks: the *constant* and the *intermittent*. Formerly, all water service was on the intermittent system, that is to say, the water was turned on for a definite number of hours in the 24, and was stored for use during the remainder of the day in cisterns. The constant service, as its name implies, is a system where the water is turned on continually day and night.

There are many disadvantages in the intermittent system, and although formerly it was almost universal, in modern practice the constant system is almost invariably adopted. These disadvantages are as follows:—

(1). The water has to be stored in cisterns which are frequently very imperfectly covered, are often a source of contamination in themselves, and are generally in such inaccessible places that they are rarely ever examined. The sanitary defects of such cisterns are frequently unknown to the occupants of a house, but those whose duty it is to examine them are aware that abominations do exist to an extraordinary degree. It is clearly of little use to filter water with much care and then allow it to be contaminated in house cisterns.

(2). In case of fire there is no pressure in the mains until the turn-cock can be found whose duty it is to turn on the water, and frequently, while this functionary is being sought for, a fire, which at the outset might have been controlled and cause little damage, has had time to spread and become a great conflagration. This has occurred again and again, both in barracks and in civil buildings.

(3). With the intermittent system the service pipes when empty are liable to become filled with sewage or other impurities through any leaky parts. The drawing off of the water causes a vacuum in the pipe, and subjects it to considerable external pressure. Hence impurities find their way through weak points. It may here be mentioned that drains for sewage ought to be at a lower depth than water pipes.

(4). Larger mains and pipes are necessary, and the cost of maintenance is greater.

The only supposed advantage of the intermittent system is that it causes less consumption of water, but experience has shown that with careful supervision and proper fittings there will be less waste with the constant system than with the intermittent.

Most English towns are now supplied on the constant system. In Germany, also. where all questions connected with water supply have of recent years received careful attention, the cities are mostly supplied on the constant system, and consumers have to pay for the water by measure, just as they would pay for gas. In Berlin, for instance,* there is an absence of house cisterns; the houses are built in flats, each supplied by a separate service pipe and meter.

The constant system, however, is only applicable where all fittings are efficient and have been found capable of sustaining proper tests. If steps are not taken to ensure this, leakage will certainly occur.

It follows, therefore, that frequent inspection of the apparatus used throughout any system of supply in a barracks or cantonment is a part of the duty of the engineers who have charge of the buildings, and it is also necessary that the whole of the system be subjected to careful regulation as regards the detection of waste in every part.

Detection of Waste.

Waste of water does not mean the use of water for other than drinking and washing purposes. In every efficient system of water supply there should be an ample margin sufficient to allow for such services, as the watering of roads and gardens and other incidental matters which do not directly come under the head of drinking, cooking, and washing.

Water is wasted where it passes away through the system into drains or into the ground without being made use of in any beneficial form whatever. A very considerable quantity of water may pass away by merely dripping from a tap. The droppings from a tap in 24 hours may often be as much as the consumption for the same period for one human being. Twenty cubic feet of water will thus pass away easily in 24 hours without attracting any notice whatever.

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* See *Minutes of Proceedings of the Institution of Civil Engineers*, Vol. CVII. 1892.

It follows from what has been just said that the very best water-fittings should be employed because, although their price at first may be greater than those of an inferior description, the saving effected by the absence of waste is more than sufficient to counterbalance the initial cost.

Another important matter in connection with the control and prevention of waste is that the branch supplying a house or a group of houses should be capable of being cut off by means of a stop-valve. The whole system of pipes is by this means divided up into wards, each thus controlled, and it may be possible to find out approximately the locality where waste is taking place without opening up the main to any extent.

Where the main pipes lie in soil not impervious to the action of water, a leak occurring anywhere will most frequently show itself by the dampness of the soil immediately above. Sometimes, however, it is seen at a little distance, having crept along the side of the pipe, where the filling in above may happen to be loose.

A successful method of following a leak has been to remove a small portion of the soil in several places near the suspected spot, and to bore down to the required depth ; the escaped water will stand highest in the hole nearest the point. Where the surface is impermeable, it is difficult to localize a leak. One method which is employed with success in some large cities is to use what are called "stethoscopes." This instrument consists of a hollow bell-shaped head of vulcanite, in which is placed a very thin disc of copper or other metal. The head is attached to a stick of wood, which, when placed in contact with a pipe in which water is flowing, conveys the sound caused by the flowing water to the metal disc and thence to the ear of the inspector. This instrument was invented to replace the use of steel bars, which were apt to cause soreness of the ear when much used. If the inspector opens the surface-box of a stopcock and applies the stethoscope, he can at once tell whether water is passing or not.

For the detection of waste, as well as for the measuring of the flow, a most ingenious meter has been invented by Mr. G. F. Deacon, M.Inst.C.E. (see *Plate* LVII.). This waste-water meter consists of a conical tube C, in which is suspended by means of a weighted wire I a disc D, which, when no water is passing through the instrument, is raised by the weight until it closes the upper end of the conical tube. As water passes through the meter in a downward direction it presses down the disc, leaving an annular orifice between it and the gauge tube sufficiently large to allow of the passage of water. When no water is passing, the weight M at the end of the wire is sufficient to raise the disc D, and close the orifice. When a steady flow is maintained, the disc will be kept at a constant level. On the upper part of the wire, outside of the gauge tube, there is attached a pencil, with guide wheels, which is elevated or depressed according to the position of the disc D. The point of this pencil presses on a recording drum P, which is driven by clockwork, and has on its circumference a paper divided into portions corresponding to the various hours of the day and night.

It will be seen that when there is no water passing through the pipe, the pencil will draw a line perfectly horizontal, but if there is any leakage in the pipe B, the disc D will be depressed and the line recorded by the pencil will be below the normal horizontal. By this means the inspector can examine each day whether there has been any water passing through the pipe at any given hour. If it appears to him from the diagram that water has been passing through during the early hours of the morning, say from 1 a.m. till 5 a.m., he will then understand that there must have been some leakage, as no one is likely to use water at those hours, and it will be his business by examination, as will be afterwards described, to make such investigation as will lead him to the ascertaining of the actual place where leakage has occurred.

Readings are taken by the Deacon meter at certain definite periods, say once a fortnight. If there is absolutely no waste the meter diagram will show a horizontal line between the hours of 1 a.m. and 5 a.m. at the top of the paper. If there *is* waste it will show a horizontal line some little distance down for those hours. As long as this waste is not excessive, say not more than 5 gallons per head per diem, no inspection may be necessary, but if it is more than this, meter readings are taken for several nights in succession, shutting off a certain ward each night, or, if it be possible, shutting off the wards for a definite time the same night. The result of shutting off a valve leading to the ward in which leakage is taking place will be to affect at once the consumption and the position of waste line. The fittings of that ward may then be inspected. If it is found that they are all right, the inspector proceeds to examine, with the stethoscope, the main at points along its course where access is possible by surface boxes. The passage of the water communicating vibration to the stethoscope will be clearly audible. It is thus possible, without opening the whole length of pipe, to locate with fair accuracy the position of a hidden leak.*

As a typical case, take the barracks shown in *Plate* LVIII., where it may be supposed that there is a Deacon's meter at or near the Tower at C, and that it has been registering leakage. To detect this leakage, it will first be necessary for the inspector to see that the mains, cisterns, etc., are full, say at 7 or 8 p.m., and then to begin his detailed examination at the far end of the barracks, say at the school near Z, about 10 p.m. He places one end of his stethoscope (which may be an iron bar, but is better to be of the regular form described above) on the pipe at the stop-cock, and the other at his ear. If there is leakage in the service pipe or taps, it will be audible when the stop-cock is open. The stop cock is then shut, and if leakage is still heard, it follows that the stop-cock must be leaking.

This operation should be repeated in the case of each branch to the married quarters at Y, and, in each case, the inspector should note in his book the hour of closing each stop-cock, and should identify it by its name-plate, or in any other way. Stop-cocks which are leaky should be noted for repairs, and any service pipe which appears to indicate the passage of water should be noted for examination, with its taps, the following day.

This, however, may not account for the whole of the leakage. It may be in the main or sluice valves. The inspector will shut the valves at E and F, noting the hour. He may either go back to the Deacon meter to see if the register is thereby affected, or he may go on testing the branches in the section from E to D, leading to S, T, etc. In any case, if the leak is in a section which has been then cut off from the main supply, the Deacon register will show it at once.

After going through the examination for the west side of the barracks, the inspector may shut it off, and proceed similarly at the east side.

The fire main should also be similarly tested.

After leaks have been discovered and made good, the tests must be repeated. The whole of the operations will possibly last for several nights in succession.

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* See *Minutes of Proceedings of the Institution of Civil Engineers*, Vol. CXVII., 1894, pp. 147 *et seq.*

The Deacon meter should be examined both before and after the test. The diagrams, of course, must be renewed daily, and carefully kept as a record.

The objection made to the use of waste-water meters that they involve a heavy initial outlay and annual expenditure for inspectors is not altogether a fair one if the meters are properly and constantly worked. It has been estimated that the quantity of waste by leakage has been found to be between $\frac{1}{3}$ and $\frac{1}{2}$ of the total amount of consumption. One 4-inch Deacon's meter is sufficient to command about 400 houses, or say a population of 4,000. Of course, the system involves constant attention and labour, but it has been proved to work satisfactorily with a well-organized efficient staff. In Vol. CVII. of the *Minutes of Proceedings of the Institution of Civil Engineers* will be found a most interesting paper, followed by a discussion, read by E. Collins, Esq., M.Inst.C.E., on the 13th March, 1894, in which the views of the most prominent English engineers of the present day are given. Among other subjects there mentioned is an expedient for detecting a waste of water in the mains without using any special apparatus. A length of fire hose is attached to a fire hydrant, and the rest of the coil placed in a bucket. The bucket is filled, and the inflowing water in the main shut off. If there is a leakage it very rapidly empties the bucket by the hydrant, and by the rate at which it empties the bucket there is a gauge of the waste going on in a particular district. By shutting off area after area it is possible to ascertain the locality of the leak. This plan has been found to answer admirably.

It has been stated that proper methods for the detection and suppression of waste are necessary for maintaining any water supply system in an efficient state. It is quite possible that a system with old and common fittings may in this way be brought to a state of efficiency without any wholesale change in all the fittings. It is, therefore, desirable that control of the waste should precede the application of new fittings to any old-established system.

The system of charging householders for the quantity of water used as measured by meters has had a salutary effect in the prevention of waste, as it is to the interest of the householder to reduce as much as possible the quantity of water passing through his system. Those who are accustomed to the ordinary system object that, by selling water through meters, people may stint themselves in the legitimate use of water, especially the poor, who in particular ought to be encouraged in its use. Against this, the advocates of the meter system reply that experience has proved that no harmful results have followed the sale of water by meter, and that it has not checked the improvement proceeding on account of alterations for the better in the general sanitary condition of the locality.

A great deal has been done of recent years in connection with water-waste preventers, water-closets, and other such apparatus for detecting any waste. Further, overflow pipes and discharge pipes are now so situated that if there is constant leakage it is generally conspicuous from outside the building. The discharge pipes of sinks and baths and lavatories now generally discharge into trapped gullies in the open air, and hence any leakage caused by defective valves is much more likely to be detected than formerly, when the custom prevailed of allowing these discharge pipes to connect directly with the drains.

Burst pipes, of course, lead to very considerable loss by leakage; they are usually caused by the freezing of water. Water expands about 10 per cent. when it freezes, and few iron pipes of ordinary sizes are able to resist the bursting action. Hence it is necessary to protect pipes from the frost, and although bursting may be prevented by allowing a gentle current to pass through, which prevents the water from freezing at the same temperature that it would do if it were still, the mere fact of the current passing means a waste of water, and hence it is better where possible to protect the pipe by some non-conducting covering, and thus prevent the temperature of the water being lowered below freezing point. Burst pipes are sometimes caused by sudden closing of taps, as pointed out in Chapter IX.

Distribution Systems.

The proper arrangement of a distribution system is not by any means an easy matter, even for a comparatively small group of buildings, such as occur in barracks. The difficulty becomes enhanced when the site is restricted, or when the level of the ground varies.

The first step is to ascertain the *quantity* likely to be required at each point of the district to be supplied. Thus, in providing for the wants of a group of barracks, it will be convenient to mark upon the general plan of buildings the positions of cisterns if such are to be employed, or other fittings if the constant system is to be used, including fire hydrants. Against each of these points of delivery the estimated quantity required in a given time should be written. The next step is to adjust the size of all the distributing mains, so that the delivery required may take place without undue loss of head by friction in the pipes. In order to do this, it will generally be necessary to sketch out approximately the line of proposed mains leading back from the positions of delivery to the service reservoir. In making this approximate plan it will be remembered that the lines of main pipe should proceed from point to point in straight lines, and that where there is a necessary change of direction, this change should be, if possible, effected by a quadrant bend, or by a bend at such an angle as can be easily obtained from manufacturers' stock sizes.

In addition to the points of delivery in various houses, an important matter is the proper location of the various hydrants for fire protection. These hydrants, as has been already said, should be situated at such positions, and at such distances apart, as will enable the whole of the buildings to be protected by streams of water in the event of fire. Thus, the positions of hydrants being assumed, it will be possible to see whether buildings are protected, by drawing circles, with the proposed position of the hydrant as a centre, and a radius of about 100 yards. If the whole of the buildings are included in the areas of the circles, or approximately so, the protection by the hydrants will be sufficient. If not so included, either the positions of the hydrants must be altered or the general alignment of the pipes changed. In making calculations for the size of the pipes, both service pipes and mains, it will probably be better to determine beforehand certain stock sizes of pipes, and having made this assumption, to work back from the point of delivery, ascertaining the amount of head required at each branch until the service reservoir is reached. It will be possible, working on the principles laid down in Chapter VII., to bring the required head, as ascertained by calculation, within the limits of the actual head available, by means of a system of trial and error. It is better to work in this manner rather than to do the converse (that is to say, starting with the given head to work out the sizes theoretically of the various pipes), because in actual construction, if the pipes are of varied sizes, there is liability of confusion, and the workmen may substitute a small pipe where calculation has intended a larger one to be used.

With regard to the estimated quantities, it will be sufficient in a small barracks if the assumption be made that two hydrants are likely to be required at any one time, and that the head of water required with a given system of pipes should be sufficient to supply the whole of the taps in any one ward running at their full capacity *plus* two hydrants discharging *their* full quantity. This may seem to be an excessive amount to be allowed for, but it must be remembered that the amount required from the hydrants is very much larger in almost any division or ward than the amount flowing from the taps, and that in the event of a large fire it is probable that more than two hydrants will be called into play. All other taps and stop-cocks will then be shut off, and the whole available supply concentrated on the three or possibly four hydrants in use. Hence it is desirable to allow for such contingencies in making the original calculations. In estimating for the sizes of pipes, it will generally be sufficient, starting at the end farthest from the service reservoir, to calculate the sizes or head required for supply through the longest system. It will be seen that if the available head is sufficient to supply what is necessary at the farthest limit of the system, it will be more than sufficient to supply all subsidiary branches. It is further important that there should be no dead ends, *i.e.*, it is necessary to connect the ends of the mains so as to permit free circulation of water. A dead end is a fruitful source of impurity, and the omission of connecting mains is very frequently false economy.

Where the buildings to be supplied are situated in localities of such configuration that the head of water necessary to supply the highest parts would cause undue pressure on the lower, it is customary to divide the whole into districts at successively lower levels, and to have independent distributing pipes branching off the main throughout each of these divisions. At every point where the branch leaves the main a *reducing valve* is introduced upon the main to moderate the pressure at each stop. The reducing valve shown on *Fig.* 157, invented by Mr. Deacon, consists of an equilibrium valve, opening downwards, through which the water flows at a rate determined by the opening of the valve, and the difference of pressure between its inlet and outlet sides. The action will be evident from the figure.

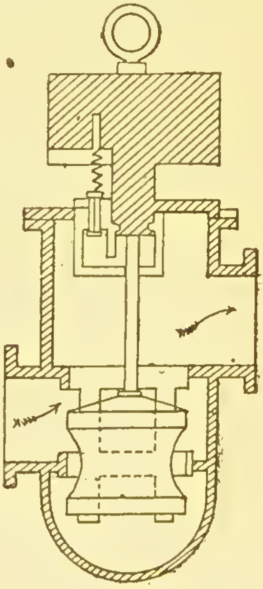
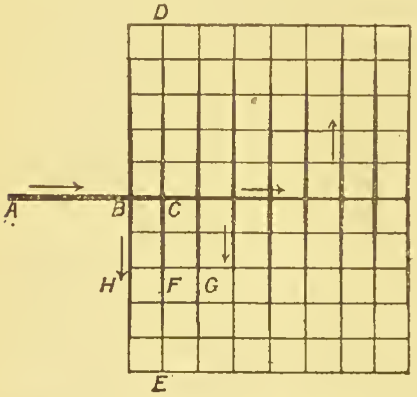


Fig. 157.

In a large cantonment or military station, undoubtedly the best position for the service reservoir is somewhere in the centre, so that main pipes may radiate out to all parts of the district to be supplied. The reservoir at Edinburgh Castle, in the centre of that city, is mentioned by Professor Burton as a typical instance of a good position. It is obviously of advantage to bring a clean water reservoir to as central a position as possible with regard to the buildings to be supplied.

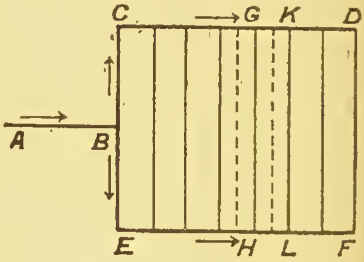
Then the area must be divided up into wards, following as much as possible the main roads or streets of a locality. Branch connections from one main artery to the next will further be necessary, and each of these branches must be governed by stopcocks, so that in case of any burst a small length may be isolated without interfering with the supply of others. It is, further, most important that the large mains should not be tapped for the direct supply of houses by screwing ferrules into them, but where it is necessary to supply water in a street passed through by a main there should be a *rider* or smaller main laid parallel to it, connected at both ends with the larger main, and governed by valves (see *Plate* LVIII.). In this way new connections can be made or repairs carried out without stopping the main supply.

Professor Burton shows in his book various systems, illustrated in *Figs.* 158 and 159 (published here by permission). The "gridiron," or interlacing, system, as shown on *Fig.* 151, has great advantages with regard to the concentration of water on any one spot and the prevention of stagnation at any part.



AB. Main pipe from supply.
CD, CE, etc. Branch mains diminishing gradually in size.
FG, FH. Distribution mains.

Fig. 158.



AB. Main pipe from supply.
BCD. BEF. } Subsidiary mains.
GH, KL, etc. Distribution mains.

Fig. 159.

A modification of this system, as shown in *Fig.* 159, is where the district is surrounded by a main of such a diameter that it is capable of supplying one-half of all the water required in the district enclosed. Each cross-pipe is of such a size that it is capable of supplying the wants of half the district on either side of it, as shown by the dotted lines.

It is somewhat difficult to work out this interlacing system where the roads or streets are irregularly arranged, and it leads to a large multiplication of sluice valves. It is not possible to lay down hard and fast rules; the broad principles to bear in mind are that dead ends should be avoided as much as possible, that the branch should be capable of supplying the maximum quantity likely to be required, that provision should be made for any future extension, and that all parts should be under efficient control in event of any accident happening.

Professor Burton considers that 4 inches is the smallest diameter which should be adopted for main pipes, and recommends 5 inches as a minimum. Mr. Fanning has suggested 8 inches. These sizes have no doubt been suggested on account of the frictional resistance which a small pipe affords when called upon to supply the large quantity of water required in case of fire. Even with the Aldershot allowance for fire hydrants, viz., 120 gallons a minute, it will be necessary to give mains at least 6 inches in diameter, unless the available head is very great, because of the friction in the pipes when in use for some time.

Whatever be the system finally adopted, it is most necessary that clear and simple directions should be prepared both for the garrison fire brigade, and for sentries, as to the valves to be shut in case of fire in any locality. The fewer these directions are the better, for they have to be practically interpreted by the British soldier, who has no technical knowledge of the subject. The directions should be prepared by the engineer officer in charge of the barracks, submitted to the General commanding for approval, and should be practised every time there is fire drill. Prompt action in getting apparatus to work, and arranging for maximum pressure in the pipes, are the most necessary objects in view in fire extinction; the first of these can be accomplished by drill and discipline, the second must be thought out and planned by the engineers.

Record plans of all the water system should be prepared as new work is being carried out, and should always be kept up to date. A copy of the record plan, showing all hydrants, valves, and fittings, should be issued to the Chief Staff Officer of the garrison, for information of the firemaster, and it should be examined and corrected by the engineers from time to time. Regimental commanding officers should, if possible, be furnished with plans and information regarding the water supply arrangements in the barracks occupied by them. This is especially important in the mounted branches. The medical authorities should be furnished with general information about the water arrangements, and special information about hospitals.

In the design of quarters, it is desirable that a special drawing of the water supply pipes and fittings be made, and that the occupant of the quarters be furnished with a copy.

Plate LVIII. shows a plan of typical barracks for one battalion with fire protection mains, and drinking supply mains. In this case the supply is continuous, there are no cisterns except those for flushing latrines, etc., and the whole system is divided up into mains and riders, each controllable by stopcocks.*

The fire mains are arranged so that by closing two valves, opposite the orderly room and the sergeant-major's quarters (marked A and B on plan), buildings which are known to every soldier, the whole of the drinking supply may at once be cut off, and the whole pressure concentrated on the fire mains. The sentries at the guard room and stable-gate would be charged with this duty in case of fire. Any man can lift a surface lid and turn a handle.

Further, a tank to hold 5,000 gallons is shown in the design, near the entrance, at a height of 30 feet. The drinking water will not pass through this tank, as it is considered that it is best to have filtered water passing direct from the supply mains to the distributing mains. In event of fire, however (when the sudden drawing off of a large quantity might be a serious inconvenience to other buildings obtaining their water from the same supply), the water from the tank would be turned on. This would be the duty of the sergeant of the guard. He would shut the bye-pass valve, and open two others.

The result would be that the mains would always be charged, and that, in event of fire, a sufficient quantity would always at once be available.

A plan of the pipes and hydrants should hang in the guard room.

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* The calculations for these are not given. They are printed separately at the S.M.E., and will be supplied to any R.E. officer on application.

Plate LIX. shows the arrangement of the mains at Allahabad, with distribution by wards. The instructions for the firemaster in each lines would be somewhat as follows :—

" In case of fire in N.I. Lines (Ward I.) close valves B, C, E, F.
,, ,, B.I. ,, (Ward II.) ,, ,, A, C, E, F.
,, ,, R.A. ,, (Ward III.) ,, ,, D, F.
,, ,, Officers' Lines (Ward IV). ,, A, B, E, F.
,, ,, Staff Quarters (Ward V.) ,, A, B, C, E, F.
,, ,, elsewhere ... ... ,, ,, D and E."

The scale of this plan is too small to show details.

MAINTENANCE.

The proper maintenance of any system of waterworks must be one of the considerations to be borne in mind in the first design. The works will require continual examination and repair, and the more continuous such repairs are, the slighter is their character. All appliances, such as hydrants, stop-cocks, meters, etc., must be periodically inspected, otherwise it cannot be expected that the mechanism will perform its proper duty. Especially is this the case with regard to sluice valves and stop-cocks, which, if not occasionally worked through their whole stroke, will tend to become clogged or rusty. Exposed metalwork should be painted, and it is important that a stock of ordinary pipes for repair should be kept in the engineer's yard or shops. These pipes may require their anti-corrosive coating renewed periodically.

Water pipes of iron are, of course, liable to corrosion, and must be properly coated with preservative material, as described in Chapter V., but in spite of care it not unfrequently happens that corrosive action does take place, rust accumulates in the pipes, and the flow of water is much interfered with. External corrosion especially takes place through *electrolysis*, where the ground in the vicinity is much used for earths in connection with electric systems. Soft water also often produces a peculiar internal formation of oxide of iron which in some cases rapidly chokes the pipe. Again, hard water sometimes deposits crystals of lime which have an equally obstructing effect.

Efforts have been made to remove some of these deposits by moveable scrapers ; the pipe is severed at intervals, and a tool of the shape shown in *Fig.* 160 is used for cutting out the deposit. The tool consists of a steel bar with a cutting point at the turned-up end. It will be seen from the figure that this is forced against the side of the pipe by a spring bearing against the opposite side. This cutter, attached to a handle formed of sections coupled to one another, is worked backwards and forwards and gradually turned round so as to remove all impurities from the interior surface. A flush of water is employed to wash the detached crust out of the pipe.

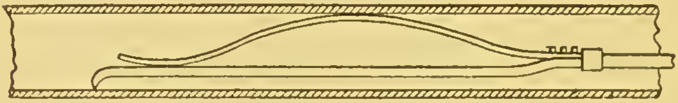

Fig. 160.

Another method, shown on *Fig.* 161, which represents a pipe scraper manufactured by the Glenfield Company, is to work the tool for detaching the rust by water pressure along the main. The tool is propelled by a disc or piston, behind which the water is admitted. The pressure forces the scraper forwards between boxes which are placed at intervals on the pipe to allow of examination and the removal of dirt. When used, this tool is introduced through a hatchway (see *Fig.* 162), the cover of which is

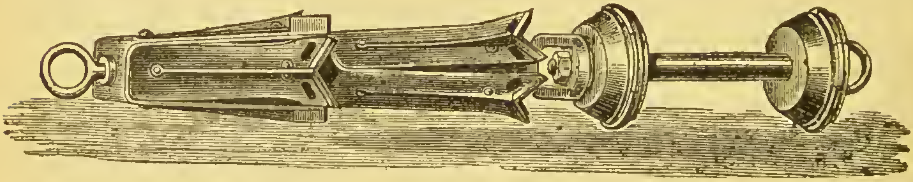

Fig. 161.

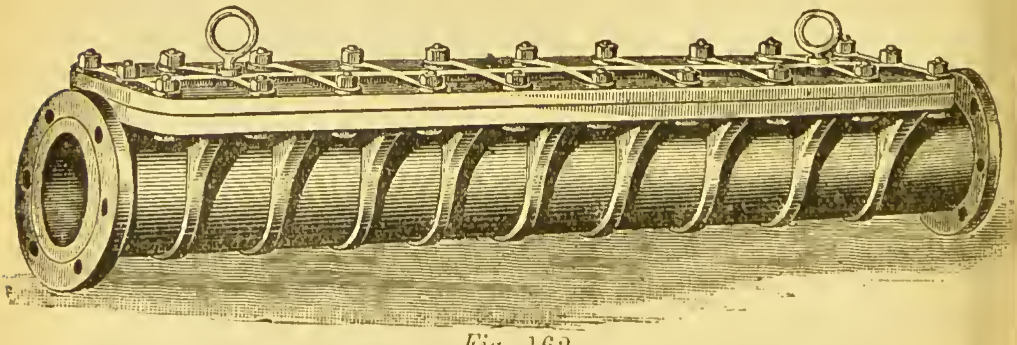

Fig. 162.

bolted on. The stop valve at the distant end of the section is shut, the main is charged, and one of the lower intermediate scour valves is opened. It will be seen that the pressure upon the pistons drives the scraper along, and the rust is shot down the pipe and discharged from the scour valve. From the above it will be manifest that liability of incrustation and obstruction points to the necessity of considerable allowance being made in the size of the pipes over and above the requirements of theory. This is one reason why cast-iron mains less than 4 inches in diameter should not be used.

PROCEDURE IN PREPARATION OF A PROJECT.

In preparing a water supply project, the report should be divided into the following sections :—(*a*). Description of source of supply from a geological point of view. (*b*). Examination of source from a sanitary point of view, including analysis of samples, and report of experts in that department. (*c*). Report of yield of proposed source. (*d*). Investigation of probable demand. (*e*). Investigation of method of supply, and comparison of any alternative methods. With this should be plans showing reservoirs, conduits, tunnels, pipes, valves and fittings, or wells, pumping establishment and engines, pipes, etc. (*f*). Proposed arrangements for purification and storage, which will probably be adopted in either alternative method of supply. (*g*). Arrangements, with calculations, for distribution, giving details of fittings proposed.

Special report should be made as to size, thickness and length of various pipes, nature of joints, and proposals for transporting them to site of works. The names of the manufacturers proposed, and the cost of the various items, should also be given.

Drawings will be required of all masonry structures, of special pipes and joints, and of any other work not easily found by reference to manufacturers' lists.

In conclusion, it may be stated that the progress of civilization in a country may be measured definitely by the perfection of the arrangements made for the supply of water to all classes of the community. Half of the food of mankind is water, and two-thirds of the preventible diseases of modern times arise from the use of impure water. The following remarks made by a writer of the present day* are, therefore, apposite, and with them we conclude this necessarily brief survey of a most important practical subject:—

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* Mr. Frederic Harrison.

"Of all problems, the most important is water. . . . Let us away with all the nastiness and stupidities of cisterns, with all their dirt, poison, discomfort, and cost. Away with the ball-cock and the bursting pipes, and all the abominations of bungling plumbers. A continuous water supply is a necessity of civilization, but free water is as much a necessity of civilization as pure water or continuous water. Water we want, unstinted, and under absolute public control for cooking, washing, and cleansing in our houses, for cleansing the streets, for fire defence, for wash-houses and public baths, for adornment and recreation."

APPENDICES.

APPENDIX I.

REPORT ON THE FAILURE OF A MASONRY DAM AT BOUZEY,* NEAR EPINAL, FRANCE.

1. The object of this dam is to impound water at the summit level of the system of canals used for inland navigation in the Eastern district of France. It is situated near the village of Bouzey, some four miles from Epinal, and there are four villages in the valley, some 10 miles long, between the reservoirs and the Moselle, into which the surplus waters drain. This valley is crossed by two lines of railway, viz., Epinal-Nancy and Epinal-Neufchateau. The bursting of the dam breached both railways and did much damage to life and property in the villages mentioned.

2. The length of the dam above ground is about 1,420 feet. It is absolutely straight. The depth of water is about 65 feet when the reservoir is full.

3. The geological formation on which it is built is described in the French geological map as *grès bigarré*, or "variable sandstone," corresponding to the later sandstones common in the British Isles. This is known to be a treacherous rock for the foundations of heavy structures, and for any work for holding water. From the strata laid bare by the rush of water at Bouzey there is no doubt that this rock was full of faults and fissures, and altogether unsatisfactory for foundation work.

4. The dam, which was finished in 1884, is shown in section in *Plate* LX. The material used was obtained in the district. Some of the stones were of excellent quality, resembling good Craigleith stone, others, again, were full of veins and appeared soft. There appears to have been no arranging of the hardest blocks in any particular part of the structure. The courses of the masonry were horizontal; there was no vertical bond at all. The mortar was of a good average quality, the lime being obtained from La Teil on the Rhone, the sand from some place in the neighbourhood having a good reputation, and the resulting mortar had evidently been most carefully mixed and prepared. It had not, however, as great a strength, by any means, as would have been the case if Portland cement had been used. As a whole, the work was good,† and bore marks of careful supervision.

5. Water was admitted to the dam to within 10 feet of its full amount for the first time on 15th March, 1884. The whole structure then bulged or bent into a curve with a chord of about 400 feet and a versed sine of nearly 1 foot, while some 2,000,000 gallons of water escaped in 24 hours. This bending of

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* This dam was visited unofficially by the writer, when on leave in France, in May, 1895. The lessons derived from the failure appeared to be so generally instructive that a report was made for the information of the War Office. This report is here published by permission.

† On this point there is divergence of opinion.

the dam caused several cracks to appear; on the up-stream side these cracks were situated at the ends of the curve, and at the down-stream side at the centre of the curve. In other words, the cracks appeared where the tension was greatest, as we should expect.

6. In 1888–9 certain consolidation works were carried out, shown by shaded lines on drawing (*Plate* LX.). As the chief engineer was of opinion that the leakage and displacement was due to faulty foundations, he constructed—*First*, an abutment A, running longitudinally throughout the entire length and founded on solid rock; *second*, a continuous buttress B, in the shape of a right-angled triangle; and *third*, an apron C, of quadrant shape, to guard against water trickling between the dam and the natural ground. This was also protected with puddle.

7. The cracks were filled up with small blocks of wood steeped in tar, the reason for their adoption being that it was thought they would yield, as it were, an elastic buffer to the expansion and contraction of the masonry due to changes of temperature. The inner surface of the dam was rendered with Portland cement mortar (of what proportions I could not ascertain) and with tar. This treatment was successful in stopping any leakage in summer, though there always was some leakage in winter. From examination of the cracks where the actual failure occurred, there is little doubt that the cracks were constantly, more or less, full of water.

8. About the centre of the dam there were three of these cracks, about 30 feet distant from one another, and extending from the top some 35 feet downwards. The central crack had a direction normal to the face of the dam; the other two were slightly inclined towards one another. There were, therefore, two blocks of masonry in the weakest part of the masonry deprived of the continuous support of the whole structure (except as regards friction) and exposed to abnormal intensity of pressure on the down-stream side owing to the internal pressure of the water in the cracks. Further, it is probable that in the early spring, after a most severe winter, the contraction of the masonry would be at its maximum, and the quantity of water in the cracks also at a maximum. Hence a very great and complicated pressure would be brought to bear on the masonry at the down-stream side.

9. The result was that on the 27th April, about 5 a.m., the sandstone crushed and the mortar on the up-stream side tore asunder. From the drawing (*Plate* LX) it will be seen that the line of fracture at the centre passed through the top of the new buttress B. The joining of the old work and the new was a source of weakness, and it is quite evident that the material was not able to stand the intense pressure thus brought into action. The two blocks above mentioned were thrown over, and now lie in the position they must first have occupied, one being broken in the fall. From careful examination of these blocks I have not the slightest doubt that failure occurred along the lines of the old cracks. It is possible to trace these by the positions of the wooden blocks.

10. I think that what then happened was as follows:—Into the breach thus formed a volume of water instantly poured, causing an extra pressure from its dynamic force upon the parts still standing. These, having no vertical bond, sheared horizontally at the point indicated by the upper dotted line in the drawing. Portions of the masonry thus torn away were hurled to distances of from 200 to 300 yards. On one side of the gap the length of the portion

thus torn away amounted to about 330 feet, on the other about 130 feet, being stopped on the latter side by the sluices, where the dam was of thicker section than usual.

11. It does not appear that there was any telegraphic communication whereby the inhabitants of the villages in the valley below might have been warned of the coming flood. If this had existed, no doubt the loss of life would not have been so great. I do not know for certain that such communication did not exist, but I did not see any trace of it.

12. The total length of the breach is about 530 feet. Its depth varies from 31 to 36 feet. If the breach had been confined to the comparatively small portion that gave way at first, the disaster would no doubt have been serious, but it would not have been attended with the terrible devastation that actually took place.

13. It is only fair to the French engineers to state that it was proposed some years ago to add a bank of earth to the down-stream side of the dam, but the project was not sanctioned.

14. I now come to consider the deductions which can be derived from this failure. Would the risk of disaster have been lessened if:—

(*a*). The *plan* had been different.
(*b*). The *section* had been different.
(*c*). The *foundations* had been otherwise arranged.
(*d*). The *construction* of the work had been modified.
(*e*). The *materials* had been different.
(*f*). The *consolidation* works had been otherwise arranged.
(*g*). Any *other addition* had been made.

I propose to examine each of these points with a view to deriving any lessons for our own benefit in any similar case.

15 As regards the *plan*, the question naturally arises, and has frequently been generally stated in the press, whether it would have been better to have built the dam as an arch, with the same cross-section. On this point it may be apposite to quote the opinion of the Aqueduct Commissioners to the Quaker Bridge dam, New York:—"In designing a dam to enclose a deep narrow gorge, it is safe to give a curved form in plan, and to rely upon arch action for its stability; if the radius is short (*i.e.*, under about 300 feet) the cross-section of the dam may be reduced below what is termed the gravity section . . . a gravity dam built in plan on a curve of long radius derives no appreciable aid from arch action, so long as the masonry remains intact, but that in case of the yielding of the masonry the curved form might prove of advantage. . . . The curved form better adapts itself to changes of volume due to changes of temperature."

The case of the Bouzey dam was not a "deep narrow gorge," and to have reduced the radius to 300 feet would have been out of the question. If, however, the radius had been about equal to the length, say 1,400 feet, the increment of length would have been about 4 per cent., and cost, say, 3 per cent. There would have been certain direct advantages. The pressure of the water being everywhere normal to the tangent of the curve at any point might be resolved parallel to, and at right angles to, the chord of the arc. The former series of resolved pressures would tend to produce compression in the up-stream face; the effect of such compression would tend to counteract any tendency for vertical cracks to open out. This compression would be entirely independent of the arch action of the dam.* And, further, such a form would also counteract the tendencies to expand and contract, due to changes of temperature.

Colonel Sir J. C. Ardagh, K.C.I.E., C.B., R.E., in a report in 1866 on Concrete Revetments at Newhaven,† points out that a fall in temperature of 10° Fahrenheit will shorten a stone wall 100 feet long by $\frac{1}{10}$ inch. With the same conditions of masonry and a fall of 30° Fahrenheit the Bouzey dam would contract 2·6 inches. Hence any alteration in design which would tend to counteract this would be of definite advantage. For this reason, I consider, though I state my opinion with much diffidence, as I am aware that it is in opposition to some very learned authorities, that it would have been advantageous to have adopted a slightly curved plan at Bouzey, provided the abutments of the curve were in selected ground and carefully strengthened.

16. The *design of the section* is, of course, an all-important matter. From the drawing it will be seen that the line of resultant pressure at each horizontal joint when the reservoir is full comes in many cases outside the centre third of the joint. It is an axiom among English and American engineers, and I had imagined among French engineers as well, that the design of a masonry dam should be so arranged that this line of pressure should always fall within the centre third. The section which would have resulted had this been the case at Bouzey is shown by the dotted black line. I have also shown the sections, to the same scale, of the dams at Vyrnwy in Wales, of Beetaloo in Australia, Tansa in Bombay, three specimens from various parts of the world of dams recently built by English engineers, and, therefore, representative of English practice. It will be seen that in comparison with them the Bouzey dam is weak. It does not, however, follow that its dimensions produced stresses on the masonry beyond the limits of resistance. To investigate this I have calculated the tension and compression at the joint of fracture, and have compared my results with those obtained by a German gentleman, a civil engineer attached to the Legation at Brussels, who was with the party that visited the work when I did. The results thus worked independently agree almost exactly. The tension per square inch on the up-stream side when the reservoir was full would be 19·1 lbs., and the compression at the down-stream side 60·35 lbs. Both these are within the possible limits of the material used. I have ascertained that the specific gravity of the sandstone was found by experiment to be 2·00, which is much lighter than any English sandstone, of which the average is about 2·4. In making the calculations the assumption was made that the dam was watertight, subject to no other stresses than the weight of the masonry acting vertically, and the pressure of the water acting normally to the inner face. It is impossible to estimate what actual stress was occasioned by the internal pressure of water in the cracks. I think, however, that it is clear that, as the dam gave way by tearing away of the joints at the upper face and crushing of the stone on the lower, the calculated results do not by any means represent the actual stresses which were produced. The effect of the uplift of the water from below would be to neutralize the weight of the masonry, producing a tension on the up-stream side far beyond the limits of the mortar. In England the ultimate limit of good hydraulic mortar is taken at 36 lbs. per square inch. Foreign engineers consider about half of this only as safe (1·26

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* See Professor Baker, *Masonry Construction*, p. 517.

† R.E. *Professional Papers*, Vol. XV.

kilogrammes per square centimètre). In any case, therefore, the Bouzey dam was at all times dangerously near the limit. It probably derived support from the unknown forces involved in the lateral cohesion of the whole, as well as from the cement rendering on the face.

17. As regards the *foundations*, I think most English and American engineers would have given a concrete bed. Sandstone in any case is a troublesome substance for a foundation, being in most cases of varying density and full of cracks. In the mill-stone grit formation in Yorkshire, where the solidity of the rock is beyond question, much trouble has recently arisen from the percolation of water through fissures. I think that if a concrete bed had been given in the first instance, the primary cause of the trouble, viz., the percolation, might have been prevented. It would probably have been wise to have taken the foundations deeper into the rock than they actually were.

18. In the *construction* of the work the arrangement of the masonry in horizontal courses, without vertical bond, was undoubtedly an element of weakness. This was more manifest in the failure of the side portions than in the overturning of the first blocks. Irregular ashlar, or rubble, is now recommended by the most eminent authorities. The stones at Bouzey were not larger than one or two men could lift. This may be well for the major portion of the work, but I think that it would have been a decided advantage to have had as well large irregular blocks in the interior of the work giving bond to the whole.

19. As regards the *materials*, the calculations of pressures given above show that the use of cement mortar at the up-stream edge, and of a hard stone, such as granite, at the down-stream edge, would have given perfectly safe results, provided there were no complications from internal water pressure. The use of different kinds of material in one structure is not usual, and is objected to by some engineers because of the risk of unequal settlement. Yet I think it is worthy of consideration whether it would not be advisable to use a hard, dense stone for the outer third, at least of the section, and lay the inner third in cement.* I think that the use of Portland cement in all structures exposed to the action of water is an engineering economy—probab y the first cost may be greater, but the ultimate risk of failure is reduced to a minimum. Still, where it is desirable to use it sparingly, that use should at least be extended to one-third of the width measured from the up-stream side. As regards different kinds of stone in the same work, the only case that I have heard of, and that has been apparently most successful, is a reservoir dam at Chemnitz in Germany.† There the hardest stones are used in the face work.

20. The arrangement of the consolidation works, 1888-9, is perhaps open to a little criticism. The amount of thrust produced at the toe of the dam hardly warrants the construction of so heavy a buttress and abutment as those shown on drawing at A and B. It seems also a pity that the buttress was not taken higher up, for it stops short just at the weakest part of the section. The filling of the cracks with pieces of wood does not commend itself. Wood is a perishable substance, and it affords no sort of tie between the parts which have been cracked. Liquid cement forced in under pressure

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* Recent experiments carried out by Mr. Deacon show that good hydraulic mortar may be used with most satisfactory results. The opinion of such an authority on this matter is most valuable (see Appendix IV.).

† See *Fig.* 30, p. 65.

would at least have adhered to the surfaces of the stone and filled up the cracks in a way that wood never could be made to do.

21. The *addition* of an earthen dam was, I understand, objected to, on the score of its being a substance entirely different from stone, and because such composite works are objectionable. But the number of reservoir embankments with concrete or masonry cores which have been built of recent years, prove that the union of earth and masonry may be attended with most satisfactory results. In this case the effect of an earthen backing would have been to neutralize the effects of changes of temperature—as pointed out in Sir J. C. Ardagh's paper, previously alluded to—as well as to give additional stability to the dam by its weight.

22. To sum up these deductions:—

(*a*). The plan might have been curved.

(*b*). The section ought to have been stronger at the part where rupture took place.

(*c*). A concrete bed might have been given, advantageously, to the foundations.

(*d*). The masonry should have been irregular rubble or ashlar, with vertical bonding.

(*e*). The stone might, for the down-stream part of the wall at all events, have been of a harder nature, and the mortar ought to have been cement.

(*f*) An earthen backing would have been of great advantage.

23. The case of the Gohna landslip in India last year proves that it is possible by means of the telegraph to give warning to the inhabitants of the valley below a suspected dam, in sufficient time to enable them to escape to a place of safety.

(Signed) G. K. SCOTT MONCRIEFF, *Major*, *R.E.*

27*th May*, 1895.

OBSERVATIONS BY COL. SIR J. C. ARDAGH, K.C.I.E., C.B., ON THE REPORT OF THE FAILURE OF THE BOUZEY DAM.

I concur in general in the deductions drawn by Major Scott-Moncrieff, but wish to call particular attention to a few points.

Par. 15.—Curvature on plan, in long dams, though the increased power of resistance to water pressure afforded by the horizontal arch may be insignificant, is of very great importance as an automatic compensation for changes of length due to temperature, and this point has not received the attention it deserves.

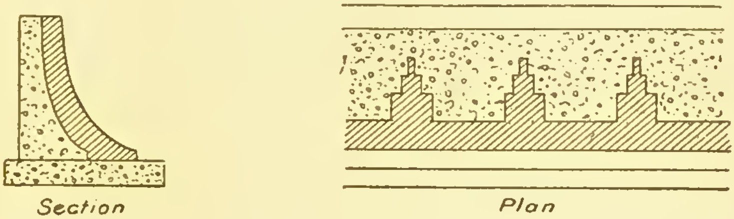
Expansion and contraction is inevitable. In long walls of brick or coursed masonry it is distributed among the joints, and the cracks are often only to be detected by minute examination. A long straight wall of concrete, however, breaks up into blocks, and the width of the cracks increases with the tenacity of the material. The limit of elasticity is reached, and rupture takes place. (This incidentally points to the conclusion that concrete walls should be constructed in blocks, so as to allow for expansion and contraction).

Had the Bouzey dam been constructed on a curve, with say arc equalling radius, the expansion and contraction would have been converted into a lateral displacement of about equal dimension, and no temperature cracks would have appeared. Probably a far flatter arch would have sufficed.

Par. 21.—The durability of a masonry or concrete impermeable dam enclosed in earth on both sides is mainly due to statical support, but very largely to protection against climatic vicissitudes.

Par. 16.—The axiom that the line of resultant pressures should always fall within the centre third of the dam is practical, but it diverts attention from the essential condition of constructive stability, *i.e.*, that the crushing strain on the outer face should not exceed the limit of safety. In a dam of large finely-bedded granite of medium height, the line of resultant pressures might pass close to the outer edge without risk, while in a dam of very great height, constructed of brick, it might not be safe to allow it to come near the limit fixed by the centre third, near the base of the dam.

The outer part of a dam should, undoubtedly, be built of a material capable of resisting heavy crushing strains, which increase with the depth, and the difficulty as to incorporating different materials in the same mass can be practically got over by having counterforts diminished in steps extending back through the dam. The rest may be filled up with cement concrete, or rubble in cement, as shown on sketch (*Fig.* 163).


Section

Plan

Fig. 163.

If the outer third of the Bouzey dam had been built of granite or other hard stone, or had it been built of a curved plan, or had the proposed outer earthen bank been added, it would in all probability not have failed.

(Signed) J. C. ARDAGH, *Colonel, Commandant S.M.E.*

31*st May*, 1895.

APPENDIX II.

SPECIFICATION AND REGULATIONS FOR WORKS IN CONNECTION WITH WATER SUPPLY AT ————.*

GENERAL.

1. The numbers on the drawings correspond with one another and with the numbers in the detailed specification.

2. Written dimensions upon the drawings to be taken in all cases in preference to scaled dimensions.

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* In this specification no works are contemplated for raising, impounding, or filtering the water, nor for works in connection with the aqueduct, other than laying pipe mains.

3. The contractor to make all necessary arrangements with the County Council, sanitary or other local authorities, waterworks company, or other officials, so as not to delay the work.

4. He shall also give all necessary notices, pay all fees, and fill up all forms that may be required by the authorities in the construction of the work.

5. The contractor shall furnish all lights, watchmen, barriers, etc., that may be required.

6. The contractor to make his own arrangements for the supply of artificial light.

7. The term "C.R.E.," wherever used in the regulations and specification, is to be considered to imply the Commanding Royal Engineer of the District, or such other person or persons as may be deputed by him to superintend the work and enforce the terms of the contract; and the terms "approved" and "directed" to mean the approval or direction of the Commanding Royal Engineer, or person deputed by him.

8. Any gravel, sand, or other useful stuff found in the excavations shall remain the property of the War Department, and if allowed to be used in any part of the works, the value of the same shall be determined by the Commanding Royal Engineer, and deducted from the amount of the contract.

9. Upon the signing of the contract, the contractor is to make arrangements to carry out the work hereinafter specified simultaneously with any cognate work, but special attention must be paid to the new connections with the main, so as not to interfere unnecessarily with the general supply.

10. The sizes of all pipes specified to be measured by their inside diameter in every case.

11. All materials and appliances used upon the work to be of the best possible quality, and good workmanship, of their respective kinds.

12. Articles of store provided by W.D. will be delivered to the contractor on the site, and he is to unpack them, close the empty cases, and prepare the same for return.

13. The contractor is to be responsible for the safe custody of all stores supplied by the War Department from the time they are handed over to him.

14. All water required for the works herein specified will be provided by the contractor, who is to make the necessary provision for the temporary service; if the water is obtained from W.D. mains, an efficient water meter is to be fixed at his own expense for registering the consumption. The water from Government mains to be paid for at rates charged by the A.S. Corps, or as may be agreed upon with the C.R.E.

15. The materials used for re-laying floors and surfaces to be similar to, and laid in the same manner as, the floors and surfaces disturbed. Should any settlement occur, the contractor shall remedy the same without extra charge.

16. The depths marked on the drawings to be to the bottom of the interior surface of the pipe.

17. All drawings, tracings, and specifications furnished to the contractor for his use are to be carefully preserved and returned to the C.R.E. within one month from the certified date of completion.

18. Where reference is made in this specification to the War Office Pattern Book, the letters W.O.P.B. will be understood as referring to the same.

19. The contractor will be entirely responsible for the correct setting out of the works, and will provide all the necessary labour and appliances for so

doing, as well as for the verification of the same, without extra charge. The verification will be undertaken by the Superintending Officer.

20. When work embraces more than one operation, each process shall be subject to examination to ascertain if it has been properly executed, and in a fit condition to be proceeded with; in addition, the work must be approved previous to each successive process.

21. The contractor is to provide such measures and weighing machines as may be directed, or required, for ascertaining the proportions or weights of materials used, and to keep the same on the works for use.

22. The contractor will not be allowed to plead verbal orders as an excuse for any omissions, deviations, or extra work, performed by him under contract, but all such orders must first be received by him in writing before he commences the same.

23. The contractor shall, if so directed by the C.R.E., remove from the site of the works embraced in this contract any agent, foreman, or workman guilty of misconduct.

24. The rates of wages to be paid under this contract are to be those paid in the district. Should daily rates be current, then the contractor shall pay similar daily rates for an equal number of hours per week worked by the artizans in the district.

25. When the site on which the contractor will be permitted to erect workshops, sheds, etc., and store his materials, has been marked out and handed over, he will, at his own expense, fence in the same, and on no account be allowed to extend his operations beyond that area, nor remove the fencing until the completion of the works.

RECORD PLANS.

Record plans to be prepared by the Contractor.

26. Complete record plans of all the work executed in this contract are to be prepared by the contractor, in accordance with the instructions contained in the "Regulations for Engineer Services," and to the satisfaction of the C.R.E.

27. The preparation of the plans is to be commenced and continued during the progress of the works, so as to ensure the correct insertion of all lines of water pipes, valves, hydrants, etc.

28. The contractor is to provide the necessary labour and materials required in the preparation of the record plans. He is to be held responsible that the plans are completed and handed over to the C.R.E. within the period fixed in the contract for the retention of the amount of money due to him, but held in reserve to cover the cost of defects, etc., so that there may be sufficient time to test the accuracy of the plans before passing the final claim for payment of any sum that may remain due to the contractor on account of his contract.

MATERIALS.

Samples to be supplied.

29. Samples of materials and workmanship proposed to be employed in the execution of the works comprised in this contract as may be called for by the C.R.E. are to be furnished by the contractor without delay. The samples, when approved, will be kept by the C.R.E., who will be at liberty to reject all materials or workmanship not corresponding with them both in quality and character.

30. All materials to be used in this contract are to be delivered where directed on the site of the proposed work, so as to allow ample time for applying the tests herein specified, and if rejected, the responsibility for any delay caused thereby in the execution of the work shall fall upon the contractor.

Materials to be tested. 31. The tests of all material shall be made by the Superintending Officer, or other person specially deputed for the purpose by the C.R.E. If the contractor desires, he or his representative may carry out similar tests at the same time as the Royal Engineers, but in the presence of the Superintending Officer, and should any difference arise in the result obtained, the C.R.E. shall decide as to the acceptance or rejection of the material in question.

BRICKWORK (*Materials and Description*).

Bricks. 32. The whole of the bricks, except where otherwise particularly specified, to be good, sound, hard, well-burnt stock bricks, uniform in size and colour. Facing and backing bricks, where used, are to be of equal thickness. All splayed or bevelled bricks are to be moulded, and not cut to shape.

Brickwork. 33. To be built where practicable in English bond and finished, where not to be rendered, with a neat struck joint. The bricks are to be well wetted before being laid, and in addition, the last laid course to be well sprinkled with water immediately before bedding the next course thereon. No false headers to be used, and none but whole bricks to be employed, except where absolutely necessary to the proper bond of the brickwork. All joints to be well flushed up at every course, and no overhand work in finishing the joints to be allowed. The walls are to be carried up regularly, so that no part be left more than three feet lower, or built more than three feet higher than the adjoining walls. Division walls are to be efficiently bonded into the main walls as the work proceeds. No four courses of brickwork to gauge in height more than one inch in addition to the thickness of the bricks themselves.

Brickwork (spaces left in). 34. Unless absolutely necessary for the safety of the structure, girders and beams are not to be pinned in, but are to rest upon stone templates, with lintels or arches above, and air spaces, 1½ inches wide, at sides and top to be left when directed. Apertures for the passage of pipes, bolts, etc., are not to be made good till after inspection by the Superintending Officer.

Brickwork Workmanship on. 35. All rough and fair cuttings, cutting out for, and pinning in, cutting chases, grooves, indents, etc., to be carefully performed, so as not to shake or injure the surrounding work.

Provision of scaffolding. 36. The contractor to provide and remove all necessary scaffolding, and to alter the arrangement and material of the same if considered desirable for purposes of safety, and ordered by the Superintending Officer.

STONEWORK (*Material and Description*).

Stone. 37. The stone used is to be free from salt, vents, sand or clay holes, discoloured surfaces, or other defects, to be close-grained, with beds and joints perfect, the whole size of the block, and of the description shown in the drawings. If required for concrete or repairs to roads, parades, etc., it is to be broken so as to pass the ring gauge specified, to be clean, free from clay, loam, or other objectionable material, and to be well washed before use if so ordered. Stone in block is to be laid on its natural or quarry bed, unless otherwise ordered by the Superintending Officer.

Workmanship on stone.

38. The whole of the stone, unless otherwise described in the bill of quantities or contractors' order, to be neatly tooled on the exposed surfaces, and to be half plain or sawn work on bed and joints of sandstones and limestones. Granite and similar hard stones to be fine axed on all exposed surfaces, and to be picked to a plane surface on beds and joints. All grooves, throatings and sinkings to be evenly sunk, of full size, with sharp arises as may be directed.

Protection from injury.

39. The whole of the masonry to be carefully protected to avoid injury, cleaned off, and left perfect on the completion of the contract.

PUDDLE (*Material and Description*).

Material for puddle.

40. All material for puddle to be absolutely free from roots, fibre, and vegetable substances of every kind, and to consist of clay, or light loam, with such admixture of clean coarse sand, or very fine clean gravel, or to be taken from such spots as may be ordered in writing by the Superintending Officer. The stones contained in the gravel are to be good rounded or water-worn stones, free from indents, and not larger than the size of an ordinary bean, or that will pass through a ¾-inch "ring gauge."*

Method of forming puddle.

41. In depositing and forming the puddle, it is to be treated as follows :— viz., in trench work, when the full depth of the excavation has been reached, and a written order received from the C.R.E. to proceed with the work, sufficient clay or puddling material is to be thrown into the trench, so as to form a layer about 10 inches in depth, and such quantity of water poured upon it, by means of a proper ladle, as shall thoroughly wet it, to the satisfaction of the Superintending Officer. The puddler or workman is then, without the least delay, to commence at one end of the trench chopping the whole layer throughout its depth, both longitudinally and transversely, so that the surface is divided into squares, with about 9-inch sides, by using an approved spade or puddling tool, and the addition of such further quantity of water as may be necessary. During this operation the puddler or workman is to trample the whole mass, and in making spade cuts shall so work the spade or tool as to allow the water added from the ladle to sink into the cuts, in addition to which, this process shall be continued until the spade or tool passes, with equal ease, through any part of the layer thus formed.

When the first course or previously formed layer has acquired solidity, the second or succeeding course may be laid on. Each course or layer in succession as deposited to be of the same depth, and receive exactly similar treatment to that described for the first layer, but care must be taken that the spade, in chopping, sinks from the upper course into that immediately beneath it.

Protection from evaporation and removal of excess of water.

42. All puddle work to be efficiently protected from the weather, as the work proceeds, to prevent the evaporation of moisture, and if an excess of water is found to exist the contractor shall drain it off or otherwise remove it, as may be directed.

MORTAR AND CONCRETE (*Materials and Description*).

Cement to be Portland.

43. All cement used, wherever required, to be Portland cement, capable of sustaining the following tests, which are to be applied within 24 hours after delivery on the works.

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* This specification of the material for the puddle is not in accordance with usual English practice, and may not suit the circumstances of the locality.

Tests* for Portland Cement.

To be fine enough to pass a sieve of 2,500 meshes per square inch, without leaving more than 5 per cent. behind.

The specific gravity of the cement shall not be less than 2·90.

If the two above mentioned tests prove satisfactory, a quantity of the cement, as shall be ordered in writing by the Superintending Officer, may be unpacked and spread upon a perfectly clean dry floor in a weather-proof building, so as to further cool the cement before use.

At the end of seven days after delivery the following additional tests may be applied to the cement that has been unpacked.

The cement is to be mixed neat with not more than 20 per cent. of water, and filled into moulds, to be immersed in water, as soon as the cement blocks can be safely removed from the moulds, which must not exceed six hours after the moulds have been filled, and after seven and fourteen days from the time of first gauging the cement for briquettes, be capable of maintaining a breaking weight, slowly applied, of 350 and 400lbs. respectively per square inch of sections. Briquettes made of one part cement to three parts sand (to pass through a mesh of 400 to the inch and retained by a mesh of 900 to the inch) will also be made, immersed in water, and these should be capable of maintaining a breaking weight of 120lbs per square inch after seven days.

When made up neat, and filled into a glass bottle or similar article, and struck level with the top, it must not, in setting, crack the vessel nor rise out of it, nor become loose in it by shrinking

When made into cakes or pats ½-inch thick in the centre and about three inches in diameter tapering off to a feather edge all round, it must show no signs of cracking, swelling, or shrinking, after immersion in water any length of time.

Sand.

44. The sand to be fresh water, river, or pit sand of angular grit, free from loam, animal or vegetable fibre. Sea sand or that obtained from tidal waters is not to be used, except where specially permitted.

Gravel.

45. All gravel or ballast to be perfectly clean, free from loam, vegetable earth, clay or other foreign matter. Any gravel required for special purposes, such as filtering material, is to be screened to the sizes ordered, and such work in connection therewith will be allowed as an extra.

Stone.

46. The stone to be used for concrete in this contract shall be the best the neighbourhood affords, and subject to the approval of the Superintending Officer as to quality and size.

Term Aggregate.

47. The term "Aggregate" when applied is, in every case, to mean stone broken to suitable sizes or clean river ballast† as delivered on site for concrete.

Term Matrix

48. The term "Matrix" is to be held to mean the cementitious material, with such proportion of sand and water added thereto as shall form a strong mortar, sufficient in every respect to fill the voids in the aggregate.

Mortar and concrete proportions of admixtures.

49. The following standard quantities and admixtures to be adhered to by the contractor:—

All concrete to consist of one part of Portland cement and six parts of clean aggregate of approved material of such a size as to pass through a ¾-inch and 1½-inch gauge, for blocks under and over 12 inches in depth, respectively, with such a quantity of sand added as may be necessary to fill up the interstices of the admixture, when properly rammed.

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* These tests are not in accordance with W.D. Specifications, but the latter are most unsatisfactory and wholly at variance with recent researches.

† "River ballast," *i.e.* rounded stones should never be used for any important concrete. It is only fit for coarse work, as the adhesion of the mortar must necessarily be most inferior.

If the foregoing standard quantities and admixtures be varied by the order of the Superintending Officer, a difference in value for the cement or sand, added or displaced, as the case may be, shall be allowed; the price in each case being for the material supplied only.

Concrete test block.

50. Before any concrete is laid in position a test block is to be made by the contractor to ascertain the quantity of sand required to fill the interstices of the concrete.

The labour and material necessary in performing this service will be allowed as an extra on this contract.

Proportion of sand in concrete.

51. The quantity of sand to be added to the aggregate, and amount of water to be used in mixing, shall be determined by the Superintending Officer, who will issue written instructions to the contractor as to the amount required in each case.*

Mixing concrete.

52. The ingredients for concrete, if made in large quantities, are to be mixed by first half filling a half cubic yard or other suitable measure with the aggregate, then adding the proportion of cement and sand sufficient to fill the interstices of the aggregate as shall have been ordered in writing by the Superintending Officer, and finally fill in the remainder of the half cubic yard of aggregate.

All material used in making concrete, whether in large or small quantities, to be twice turned over dry, on a clean platform or floor, then shovelled to a third heap, at the same time adding from the rose of a watering pot such a proportion of water as shall be decided by the Superintending Officer.

The time that shall elapse between the first addition of water to the dry material and its final deposition in excavations, trenches, or other situations, including the completion of ramming, to be fixed by the Superintending Officer, and is on no account to be exceeded.†

Concrete to be lightly rammed.

53. After the concrete has been deposited in its position it is to be lightly rammed with wooden beaters of approved pattern, until the moisture appears in a thin film on the surface. It is then to be covered over with sacks or rough canvas to protect it from the atmosphere. When the temperature is 60° Fahrenheit and over, the sacks are to be well wetted before being laid into position, when between 40° and 60° they are to be used dry, but if the temperature be less than 40° Fahrenheit, no concrete is to be made or deposited under any circumstances.

Precautions during setting.

54. The greatest care to be observed so as not to disturb the concrete whilst setting. Should it be necessary to pass over it when newly deposited, planks are to be laid down carefully for that purpose.

55. All surface work is to be kept damp for at least fourteen days after its formation, by flooding it with water or covering it with damp sawdust, sand, or otherwise, as may be approved; the sand or the covering material to be kept damp during the period named by sprinkling it with water from the rose of a watering pot.

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* I think on the whole this would result in a more satisfactory concrete than specifying one cement, two sand, six broken stone.

† This is important. A contractor should not be allowed to mix his concrete one day and deposit it the next.

Dry surfaces to be wetted

56. All edges or surfaces where the work has been left off, that have become dry, are to be swept to remove any dust, and to be well wetted before recommencing work, in addition to which, efficient bonding by projecting stones, set in the adjoining layers, is to be effected. Concrete which has been in position for twenty-four hours or more should also be picked on the surface to form a key for new layers.

Allowance for hand packing stone.

57. An allowance of five per cent. on the price of the total quantity of concrete, laid in more than one layer or course, is to be provided by the contractor for selecting and depositing the bond stones referred to, and also any difference in cost between these stones and the aggregate will be allowed as an extra for material supplied only, but the stones used are not to be considered as an addition to the bulk of the concrete.

Exposed and finished surfaces.

58. All exposed surfaces to be brought to an even and finished state, to be free from discoloration, of uniform color, and on completion to be protected from injury by traffic or falling material, etc.

TIMBERWORK *(Material and Description).*

Timber.

59. The timber used in this contract to be of the best description of their several kinds, not having been previously used, except in the case of shoring, sound, thoroughly seasoned, and free from large or loose knots, shakes, wanes, or other defects, to be entirely free from sap, and where scantlings are to be fixed in the rough they are to have all the sides sawn die square with sharp angles. Oak or elm, where specified in the drawings and quantities, to be of the best English growth unless otherwise specially ordered. All other timbers to be of the best Memel, Riga or Dantzic fir equal in quality to first-class Baltic shipments.

Allowance for workmanship.

60. One-sixteenth of an inch to be allowed for each wrought face on all timber.

The length of all scantlings in lineal measured work, or if reduced to superficial or cubic measure when measured in detail, to be taken at the extreme points including tenons and allowance made for scarfs, except in the above mentioned case, the net lengths, breadths, thickness and girths ordered are to be supplied, and no allowance is to be made for any dimensions beyond those demanded.

Centering, Casing and Shoring.

61. Centering, casing, scaffolding and shoring whenever provided is to become the property of the contractor when the work is completed, but is not to be cased or removed until a written order is received. They are to be of good design and construction, suitable in every respect to the purpose for which they are intended, and subject to the approval of the Superintending Officer.

ASPHALTE WORK.

Asphalte.

62. Any asphalte work that may be required to be executed by the Seyssel Asphalte Company in accordance with the terms of their contract with the War Department, and independent of this contract.

The contractor is to give due notice when the work performed by him is ready for the asphalte, and also to render every facility for the execution thereof.

IRONWORK *(Material and Description).*

Cast Iron.

63. Cast-iron articles to be of good soft grey iron from the second melting,

cast sound, clean, and free from all defects; holes to be drilled concentric, and countersunk if required.

Wrought Iron.

64. Wrought iron to be soft and of close silky fibre, thoroughly well made, free from lamination, coarse crystals and blotches, and of quality known as Best Best, or Best Best Best Staffordshire, or other approved kind as stated in the bill of quantities or as may be ordered.

Steel.

65. The steel to be used in this contract to be soft mild steel containing not more than ·5 per cent. of carbon, tough, malleable, elastic, uniform in texture, free from flaws, easily tempered, of Bessemer or Siemens-Martin manufacture, and capable of bearing the tests hereinafter specified.

Smith's Work.

66. Smith's work to be forged clean from the anvil with flatters, swages, or rounding tools, neat chamfers, or evenly diminished, etc., as may be required; all welds, turns, and sets to be sound; all screwed work to have full threads (internally and externally); all bolts to be long enough for two full threads to project beyond the nut, and all bolts in connection with any wood work to have large washers under heads and nuts; all holes to be drilled cleanly and burrs to be cleaned off; holes for screws to be countersunk if required, all countersinking to be concentric, all coach screws and screw bolts to have hexagonal heads and nuts, and Whitworth threads.

Rolled iron and steel joists.

67. Rolled iron and steel joists, etc., of I.L.T., or other form, are to be of English manufacture, and of the stock sizes of an approved firm of manufacturers.

Patterns and moulds.

68. All patterns or moulds for iron or steel work that may be required in executing this contract to be prepared in absolute accordance with the detailed drawings, and submitted to the Superintending Officer for approval previous to the casting being made, or the wrought iron or steel shaped.

Tests for wrought Iron.

69. All iron or steel to be subject to such test or proof by tension, hydraulic power, falling weight, lever, or other means as the C.R.E. may consider necessary, and when so tested shall be equal to the following standards:—

Tensile test.

Description.	Wrought Iron, B.B.			Wrought Iron, B.B.B.			Remarks.
	Ultimate Tensile stress per square inch.	Contraction of area at fracture.	Elongation.	Ultimate Tensile stress per square inch.	Contraction of area at fracture.	Elongation.	
	Tons.	Per cent.	Per cent.	Tons.	Per cent.	Per cent.	
Bars, round or square ...	23	30	30	24	40	40	
Bars, flat	22	25	25	23	33	35	
Angle	22	18	25	23	30	35	
Plates grain lengthways ...	20	12	10	22	18	12	
Plates grain crossways ...	18	7	5	19	10	7	
Sheet grain lengthways ...	20	12	10	22	18	12	
,, ,, crossways ...	19	7	5	19	7	7	

NOTE.—The percentage of elongation is to be taken in preference to that of contraction of area of fracture.

Forge Tests. Plate and sheet iron to be bent either hot or cold, with or across the grain on a cast-iron rectangular slab, having the corners slightly rounded off. The angle through which the plate or sheet should bend without cracking is shown in the following table, and the number of degrees therein given is the angle or distance through which the plates are to be bent, commencing at the horizontal, and is not the angle between the two sides of the plate after it is bent.

	Hot.	Cold.				Hot.	Cold.
	THICKNESS.						
	1 inch and under	1 inch	¾ inch	½ inch	¼ inch	under ¼ inch	under ¼ inch
B.B. Grain lengthways	125°	15°	25°	35°	70°	125°	90°
B.B. Grain crossways	90°	5°	10°	15°	30°	90°	40°

Other descriptions of iron, except rivets, to be tested for brittleness by bending and flattening when hot, and notching and breaking across the grain when cold, to show the quality of the iron. In the latter case the method of applying the stress necessary for fracture shall be ordered by the Superintending Officer and is to be appplied only to bars over half an inch in thickness.

Rivet Iron. 70. Rivet iron when cold to bend double without showing any sign of fracture. The heads of rivets when hot to withstand being hammered down to less than ⅛-inch thickness without cracking at the edge. The shank to withstand having a punch of two-thirds its own diameter driven right through it when hot without cracking the iron round the hole.

Tests for steel. Tensile tests 71. Strips of steel cut lengthways, or for plates either lengthways or crossways, and in the case of round bars, a piece from the bar to have an ultimate tensile strength of not less than 26, and not exceeding 30 ton per square inch of section, with an elongation of 20 per cent. in a length of eight inches.

Forge and welding tests. 72. Such reasonable forge tests both when hot and cold as the Superintending Officer shall order.

Tempering tests. 73. Strips cut lengthways as for plates lengthways or crossways, 1½ inch wide, or in round bars a piece from the bar, heated uniformly to a low temperature, cherry red, and cooled in water 82° Fahrenheit, must stand bending in a press to a curve, the radius of which is three inches. The pieces cut for testing are to have their sharp edges taken off, to be cut in a planing machine, and to be at least eight inches in length.

Buckle plates and girders. 74. To bear   tons concentrated load at the centre without permanent set, and of   tons at centre without fracture.*

Term "Permanent Set." 75. The term "permanent set" herein applied to, means any change of form or increase in length, no matter how slight, that is rendered permanent by the application of loads or stress.

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* These amounts will vary with span, etc.

Cost of tests

76. For the above test, portions of the iron or steel work will be taken, and the expense, if any, entailed thereby, will be allowed as an extra on the contract.

Expansion and contraction of iron and steel.

77. Every care to be taken to provide ample means for the expansion and contraction of iron or steel when used in large sections, especially where in contact with concrete, masonry or brickwork.

Cast-iron pipes.

78. All pipes over 1½ inch in diameter to be cast iron, cast vertically, and to be of the dimensions and weights hereafter specified, uniform in section, smooth in bore, free from flaws, and, being tested by being lightly struck with a 4lb. hammer, treated with Dr. Angus Smith's protective process as follows :—

Coating iron pipes with Dr. Angus Smith's solution.

79. The pipes are to be thoroughly scraped and brushed free from sand, scale and rust to the satisfaction of the Inspecting Officer.

They are then immediately to be immersed in a bath of coal tar pitch prepared in the following manner, viz., the tar is to be boiled until the naphtha is entirely removed, and it attains about the consistency of wax, after which five or six per cent. of mineral oil (coal tar or pitch oil) is to be added. This composition is to be carefully heated in a suitable vessel to a temperature of not less than 400 degrees Fahrenheit, and so maintained during the dipping of the pipes, which must also attain the same temperature at least ten minutes before their removal from the bath.

When the process is complete the pipes are to be carefully lifted vertically out of the bath, so that the surplus composition may run off, leaving a thin uniform coat (about $\frac{1}{100}$ inch in thickness) on all surfaces of the iron.

The pipes are then to be left to dry on skids.

When the pipes are cold, the coating must be tough and firmly adhering to the surface of the iron, without any tendency to scale off. One or two more pipes shall then be selected by the Inspecting Officer, and immersed in clear water for at least 24 hours, and if the coating is found to be perfect, and the water uncontaminated by the tar, the process will be considered to have been satisfactorily performed.

The tests are to be applied on the contractor's premises, at his own expense, and he will be held responsible for the perfect application of the process to the satisfaction of the Inspecting Officer of the War Department.

The approval of the Inspecting Officer shall, however, in no way release the contractor from the responsibility of having to make good at his own cost any defects which may afterwards be discovered.

NOTES.—It is essential to the proper performance of the foregoing process that the pipes shall be free from rust, and as it is difficult to get rid of rust after oxidation has set in, it is desirable that the dipping of the pipes shall be performed before, or immediately after, they leave the foundry ; and when this is inconvenient, or impracticable, they should receive a coat of linseed oil to protect them until they are ready for the tar bath.

As the pitch will become thicker and deteriorate after a number of pipes have been dipped, fresh oil and other material will require frequently to be added, and occasionally, as when the material becomes hard and brittle, like common pitch, the vessel must be entirely emptied of the old contents and refilled with fresh material.

Pipes. Cast iron.

80. All cast-iron pipes to be from the second melting of No. 3 quality pig iron, cast vertically in dry sand, socket down, uniform in section and thickness of metal throughout, free from cinder or inferior iron, and of the weights* and size shown in the following table, or as may be ordered :—

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* These weights are those for a 600 foot head (*vide* tables, Chapter V.)

Internal Diameter in Inches.	Thickness of Metal in inches.	Normal weight of pipe inclusive of socket.						Length of pipe exclusive of socket.		Inside depth of socket in inches.	Inside diameter of socket in inches.	Lead joint for socket pipes.		
		Socket joint.			Turned and bored joint.							Thickness in inches.	Depth in inches	Weight in lbs.
		cwts.	qrs.	lbs.	cwts.	qrs.	lbs.	feet	ins.					
2	·380	0	2	4	0	2	6	6	0	3	3·260	¼	1½	1·4
3	·400	1	0	24	1	0	26	9	0	3½	4·300	¼	1¾	2·3
4	·420	1	2	16	1	2	20	9	0	4	5·465	5/16	2	4·7
5	·451	2	0	22	2	0	27	9	0	4	6·527	5/16	2	5·0
6	·481	2	3	0	2	3	6	9	0	4¼	7·537	5/16	2¼	6·5
7	·496	3	1	8	3	1	15	9	0	4¼	8·617	5/16	2¼	7·7
8	·510	3	3	14	3	2	22	9	0	4¼	9·645	5/16	2¼	8·2
9	·532	4	2	0	4	2	9	9	0	4½	10·689	5/16	2½	10·4
10	·555	5	0	7	5	0	17	9	0	4½	11·735	5/16	2½	11·5
12	·627	7	0	0	7	0	12	9	0	4½	14·004	⅜	2¾	18·0

NOTE.—The minimum weight to be allowed for the pipe lengths in the above table shall be 1 lb. per inch in diameter in each case, *e g.*, 2 lbs. less in the case of 2-inch pipe length, 3 lbs. in a 3-inch length, and so on. If lead joints are used, with turned and bored jointed pipes, the quantity of lead in each joint to be approximately three-fourths of the weight of lead shown in the table for similar sized socket pipes.

Cast iron flange pipes.

The proportion of flanges for cast iron pipes to be as follows :—

Diameter of pipe in inches.	Diameter of flange in inches.	Thickness of flange in inches.	Number of bolts.	Diameter of bolts in inches.	Diameter of circle of bolts in inches.
2	5¼	½	3	7/16	3¾
3	6½	⅝	4	½	5
4	8	⅝	4	9/16	6¼
5	9¼	¾	4	9/16	7½
6	10½	¾	6	9/16	8¾
7	12	¾	6	⅝	10
8	13¼	⅞	6	⅝	11¼
9	14½	⅝	6	⅝	12½
10	16	1	6	¾	13½
12	18¼	1	5	¾	16

The branches, junctions, bends, etc., to be of corresponding thickness, weights, etc., as given in the foregoing tables.

Tests for cast-iron pipes.

81. The whole of the pipes, bends, valves, etc., forming the mains and sub-mains, are to be tested to withstand a pressure of 260lbs.* to the square inch,

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* 600-foot head.

and during the time the necessary pressure is being applied, to be tapped with a hammer in such a manner as to represent shocks caused by the turning off of valves or cocks. All pipes that have been tested and passed to be numbered consecutively in white paint, and those that are rejected to be broken up in the presence of the Inspecting Officer.

Method of jointing C.I. pipes.

82. The pipe sockets in the case of socket-jointed pipes to be effectively caulked with white or untarred yarn, and afterwards run with cotton lead. The turned and bored jointed pipes, after being efficiently connected, are, unless otherwise ordered, to have the sockets run with molten lead. The lead in both cases to be set up with a caulking tool, so as to have a clean socket end.

Wrought-iron pipes.

83. The supply or service pipes for hot and cold water to be of galvanized wrought iron, but or lap-welded pipe, connected with sockets of strong make, capable of standing a hydraulic pressure of 400-foot head of water,* with requisite fittings, such as bends, tees, ferrules, sockets, equal or reducing as may be required. To be put together with red lead and to be properly screwed. All connections to cisterns to be made with screw unions and fly nuts.

Weight of W.I. pipes.

84. The weight of wrought-iron galvanized pipes to be not less than the following, viz. :—

PER 10 FEET LINEAL.						
⅜ inch	½ inch.	¾ inch.	1 inch	1¼ inch	1½ inch	Internal diameter.
6	8	13	19	25	34	Weights in lbs.

LEADWORK *(Material and Description).*

Lead.

85. The whole of the lead for pipe joints to be the best new pig lead, free from sand, and that for other purposes to be the best milled sheet lead, free from flaws, or other defects, and of the various weights per foot superficial specified in bill of quantities.

Material for securing lead in position.

86. All copper nails, lead tacks, lead wedges, brass screws, etc., material necessary to make the work secure and perfect in every respect is to be supplied by the contractor.

Lead coverings.

87. All lead coverings shall be laid to the complete satisfaction of the Superintending Officer.

Lead pipes.

88. Lead pipes are only to be used as supply and discharging pipes from flushing cisterns and wastes from safes. They are to be uniform in thickness throughout, and not less than the following weights, viz. :—

	Discharging and waste pipes.				Supply pipes.			
Inside diameter	2″	1½″	1¼″	1″	¾″	⅝″	½″	⅜″
Lbs. per yard.	25	19	16	11	11	9	7	6

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* 173 lbs. to the square inch.

Plumber's Work.

89. The contractor to make all properly wiped plumber's joints, perform all bossings, dressings, and all other labours required to complete the whole of the work in best and most workmanlike manner.

PAINTING *(Material and Description).*

Paint or colour, solvents and driers.

90. The paint or colour to be strained free from skins and all extraneous matters previous to its being laid on.

The basis for all paint for woodwork, unless otherwise ordered, to be composed of best genuine white or red lead.

The colouring pigment to be natural earths of best quality and finely ground.

The driers to be litharge or other approved material.

The oil, unless otherwise ordered, to be the best "Baltic linseed oil," and the turpentine best American, free from adulteration.

The paint for ironwork to be Calley's Torbay (oxide of iron) paint.

The paints to be mixed on the site of the works, in the proportions most suitable for the material to be covered.

The colours are to be specially approved of by the C.R.E., and laid on in uniform tints as directed. Each coat to be of a different tint, and to be certified for by the C.R.E., before the succeeding coat is applied.

Painter's work.

91. Previous to painting, the woodwork, if wrought, is to be rubbed down, knotted with the best patent knotting, to be carefully stopped, and after each coat is to be again rubbed down, care being taken that the last or finishing coat of each distinct tint is of uniform colour throughout. The number of coats in oil, to be applied to wood or other work, shall be as specified in the bill of quantities.

All ironwork to be efficiently cleansed from rust, and, except as hereafter described, painted, two coats on the site before being put together and fixed in position, after which it is to receive a third coat.

Bottom of tank in WaterTower

The undersides of plates to floor, girders, etc., are to be paid over with a composition, consisting of four parts Venetian red, one part red lead, with Stockholm tar sufficient to make the mixture into a stiff paste, which is to be prepared as follows:—The Venetian and red lead are to be thoroughly incorporated together, sufficient Stockholm tar being added to make the mixture into a stiff paste; it is then to be applied with a trowel to a thickness of an eighth of an inch. Powdered cork is then to be incorporated to a depth of about $\frac{3}{8}$ of an inch by being pressed into the mixture with a heavy float or beater (similar to that used by the asphalter). Care must be taken that only sufficient tar is used to make the mixture into a stiff paste, as if too much tar is used the mixture will not harden.

Chemical Analysis of Material.

92. Should it be deemed desirable to submit any, or all, of the materials for analysis by the War Department chemist, samples, in such quantities as may be directed, will be supplied, in suitable vessels or cases, by the contractor for that purpose at his own expense.

WATER SUPPLY.

Excavations.

93. All excavations for water or drain pipes, pits, foundations, or other purposes are to be of the several widths and depths required. Level all the trenches, or cut them to a regular inclination, fill in, level and ram any defective parts in trenches, behind walls, and over and around pipes in layers

of six inches, the smaller stuff to be selected for filling in immediately round the pipes.

Shoring excavations.

94. Shore the sides of all excavations, if required, in such a manner as shall be sufficient to secure them from falling in.

Grass surfaces.

95. Where the pipes cross grass surfaces, the sods are to be carefully taken up and stacked, and the soil immediately below the sods is to be removed, reserved and afterwards replaced in the same position. When the pipe trenches have been filled up, the sods are to be relaid, twice beaten and rolled, the joints to be sown with grass seed, and well watered until the seeds have taken root.

Surface of roads, parades, etc.

96. The metalling found in making excavations at surface of roads, parades, paths, and similar formations, is to be stripped off and kept separate from the other materials excavated, until the pipes are laid and trenches filled up, when it will be re-spread upon the surface and well rolled.

Excavations to be kept free from water.

97. All excavations shall be kept free from water during the progress of the work, the contractor providing all necessary apparatus and labour for that purpose.

Removal of superfluous earth.

98. All superfluous earth, rubbish, etc., to be carted away as it accumulates, either off the W.D. premises, or to such other site as the Superintending Officer may direct.

Foundations not to be laid until ordered.

99. No foundations to be laid until the excavations have been approved, and an order in writing given for the work to be proceeded with. In the event of the contractor proceeding with the foundations without such order, he will be called upon to remove the same at his own cost.

Position of cast iron mains.

100. Cast-iron water mains to be laid where shown on plan, together with all main or sluice valves, and fire valves or hydrants as may be necessary, or hereafter described. No pipe to be less than 3 feet below the surface, and the ground to be excavated to a sufficient depth below the levels shown on the plan to admit of this. Furthermore, the socket ends of all pipes are to be laid against, or in the opposite direction to, the flow of water.

Position of service pipes

101. No service pipe is to be laid under ground at a less depth than 30 inches from the surface.

102. The cold water pipes above ground to be firmly and neatly secured to walls, timber, etc., with W.I. brackets, pipe-hooks, or as otherwise approved, and are to be covered with No. 3 quality non-conducting dry hair felt,* bound round with copper wire, enclosed in deal casing, and of the undermentioned sizes :—

From water main to cistern to be 1½-inch pipe.

From cistern to { sinks—1-inch pipes.
feed cisterns—½-inch pipe.
W.C. flushing cisterns—¾-inch pipe.

Size of service (supply) pipes.
Size of service (delivery) pipes.

Elbows not to be used.

103. No wrought-iron elbows will be allowed, bends only to be used, and should a reduction in the size of the pipe take place at an angle, the bend is to be of the size of the inlet or largest pipe.

Position of rising mains and service (supply and delivery) pipes.

104. All rising mains and service (supply and delivery) pipes to be kept as much as possible on inside walls, at a distance from windows and ventilating openings. Where in exposed positions, they must be protected from frost by

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* Or patent silicate cotton.

wrapping them with hair felt and enclosing them in wood casing (as described in clause 102).

105. All service (supply and delivery) pipes inside the buildings to be fixed so as to be easy of access, with a proper inclination to prevent air lodging in them, the vertical pipes, as a rule, to be carried up in the angles of walls; should any pipes be placed in plastered walls, they are to be inserted in chases and cased with ¾-inch wood casings, ledged and secured in narrow rebated grounds, with 1½-inch brass screws.

Position of hot water service pipes

106 No hot water pipes to be fixed so as to pass through any water closet, unless the arrangement is unavoidable. If unavoidable, the holes through which the pipes pass must be grouted with cement to avoid the passage of effluvia into adjoining rooms. Ceilings and floors through which any pipes pass must be made thoroughly sound, so as to prevent the passage of air. All hot water pipes to be wrapped with two thicknesses of No 3 hair felt, and cased in as previously described (see clause 102).

Method of securing wooden casings.

107. No wooden casings enclosing pipes or other appliances must ever be nailed up, but must be so fixed that they can be easily taken down. All casings to be painted four coats in oil, or grained to match other decorations.

Working hours.

108. The work in connection with mains and branches must be executed in such a manner, and during such times, as may be calculated to interfere as little as possible with the continuity of the supplies to the various buildings.

Precautions to lessen loss of water to existing buildings during execution or alterations.

109. With a view of preventing, as far as possible, inconvenience resulting from temporary loss of water in buildings, the extent and method of laying each section at length of main, &c., are to be approved by the Superintending Officer, and the contractor must use all possible dispatch, when necessary, in the execution of the work, taking precautions before disconnecting any existing supply for alteration, to have in readiness all necessary pipes, connections, and fittings, for the speedy completion of the alteration.

110. Temporary connections of old to new pipes must be made when necessary, and as directed.

Valves and Fittings.

Valve for cast-iron water mains generally.

111. All valves fixed on cast-iron water mains to be connected thereto by means of flanged joints, with such suitable short lengths of pipe as are shown in the Contract Drawings.

Junctions with all mains to have valves at the junctions.

112. All junctions with mains to be provided with sluice valves, with flanged ends, and each valve is to have one spigot and one socket piece bolted to it; branches for future extensions to have a cap on the spigot-ended piece which is to be bolted to the end of the valve.

Sluice or main valves.

13. To be high pressure valves, of the kind made by J. Stone & Co., and known as the Improved Oval Pattern, Class A.A., or of other approved manufacture, with four facings of gun metal, of the full bore of the main, with flanged ends, and proved to a pressure equal to that specified for the mains.

114. The valves to be fixed, where shown on plans, by flanged joints, each bolted with the number of bolts specified in the table (clause 80), and to be put together with a flange of asbestos packing, or if so ordered, a flange of 5-lb. sheet lead with red lead cement, and gasket.

Surface box covers to sluice or main valves.

115. All sluice valves to have strong cast iron surface boxes, with wrought iron hinged lid (Brighton Pattern), J. Stone & Co.'s Catalogue, having raised letters "S.V." cast on.

Wash-out valves.

116. The sluice valve provided as a "wash-out," where shown on plan, to be fixed in a chamber of 9-inch brick-work in cement, 2 feet 7 inches by 1 foot 9 inches, resting on 6 inches of concrete, and covered by a heavy manhole door, similar to those provided in Plate 114B, W.O.P.B.

Drains from wash-out valves.

117. A 6-inch stoneware outlet drain, for the purpose of emptying the water mains, to be laid where shown, to discharge with open end, into the surface gulley at YY.

Fall of mains to wash-out and fire valves.

118. All water mains to be laid with a slight inclination towards the "wash-out" valves, or to fire hydrants, at sufficiently low level to act as wash-out valves, so that the mains may be emptied in case of repairs, and for cleaning purposes.

Hydrants or fire valves.

119. To be of J. Stone & Co.'s manufacture, 2½-inches diameter, with stand pipes, surface boxes, etc., complete, *vide* Plate 93A, W.O.P. Book. The hydrant and stand pipe to be screwed to the Local Fire Brigade thread, and to be provided with gunmetal connections to fit the *old* and *new* Metropolitan thread.

Surface box covers to hydrants.

120. Surface box covers to hydrants to be large, strong, cast iron, lettered *Fire Hydrants*, in accordance with Plate 93A, quoted above.

Self-acting air valves on main.

121. Double air valves to act automatically under pressure, and allow the small quantities of air to escape, which occasionally accumulate under pressure at the summits of mains, are to be fixed where shown in drawings. To be of the pattern known as double self-acting air valves, Messrs. Bateman & Moore's patent, see Messrs. Guest & Chrimes or Glenfield Company's catalogue, with cast-iron street cases and covers complete.

Stop or governing valve on service (supply) pipes.

122. All service (supply) pipes to have fullway screw down stop valves (as shown, No. 1197, in Messrs. J. Stone & Co.'s catalogue) on their course where they enter any building, covered by cast-iron surface boxes, set on brickwork in cement.

Ditto on service (delivery) pipes from cisterns

123. Service (delivery or discharging) pipes to have fullway screw down stop-cocks, of approved kind, near their junction with the cisterns. These service pipes must be so fixed that they can be emptied at the lowest tap or other outlet.

Bib valves.

124. All bib (*i.e.*, discharging or delivery) valves to be brass screw down, Ham's patent (see No. 1236 Messrs. J. Stone & Co.'s catalogue), or other approved manufacture, capable of being repaired without the necessity of turning off the water supply.

Waste water meter chamber.

125. The waste water meter chamber is to be constructed as shown in detail in Drawing No. ......, and the water main passing through the chamber is to have a short length of pipe, with two flanged joints, for detaching when desired.

Water meter

126. The water meter at ....to be fixed only, together with the necessary connections, bye-pass, cover, and frame as described in No. ...... drawing.

Turncock's keys.

127. Two sets of wrought-iron keys to be provided to fit the spindles of all the above mentioned stop, sluice and fire valves.

Surface boxes.

128. The surface boxes to be fixed on small brick (in cement) shafts ; resting on a concrete foundation as described below.

Brick pits for service (supply) stop valves to buildings.

129. To be 14 inches by 14 inches surface area in the clear, and of such depths as are shown in the detailed drawing—sides to be one brick thick, built fair in cement mortar, and jointed on the outside, and corbelled over to form a good seating for cast-iron surface box, and to have a York stone bottom, 2 feet 8 inches by 2 feet 8 inches, and 2½ inches thick, including all digging, filling and removing, and surplus earth.

Concrete seatings to surface boxes to ditto.

130. The cast-iron surface boxes to be encompassed in Portland cement concrete (composed of half Portland cement and half granite chippings), about 18 inches by 18 inches over all, and 4 inches thick, formed in position and made good up to flanges, etc., the earth surface to be levelled or formed around same.

Brick pits for hydrants or fire valves and sluice or main valves.

131. Brick pits for hydrants of one brick sides, built in cement, 27 inches by 14 inches by 24 inches, and of such depths as are shewn on the detail drawing, with Portland cement concrete bottom 4 inches thick, trowelled smooth, the pit to be built fair inside and rendered in cement, and corbelled over to form a good seating for the surface box.

Concrete seatings to surface boxes to ditto.

132. Encompass the surface boxes with Portland cement concrete (half Portland cement and half granite chippings), 3 feet 9 inches by 2 feet 8 inches over all (want in centre, of 1 foot 9 inches by 10 inches), and forming in position, etc., as before described.

Name plates

133. Provide and fix on the nearest building, in the most conspicuous position, cast-iron name plates, J. Stone & Co.'s., No. 4, painted and lettered, to indicate positions of hydrants, sluice valves, and service stop valves.

Cisterns.

134. Storage cisterns holding less than 300 gallons to be of galvanized iron, ⅛-inch thick, rivetted at top, bottom and angles to 1½-inch by 1½-inch by ¼-inch L iron, with ⅜-inch rivets, 1½-inch pitch, fitted with a 2-inch overflow pipe connected as near the top as possible, discharging free through the nearest outside wall in an approved position, the end being provided with coarse wires to keep out small birds. A piece of T iron, 1½ inch by ¼ inch, is to be fitted at the top, about 1 foot 8 inches from the end at which the supply pipe is connected. The portion of the cover immediately over the ball-cock, extending the full width of the cistern and 1 foot 8 inches in length, is to be hinged so that it may be easily removed when required for examining the ball valve, cleaning the cistern, or other purpose.

135. All pipe connections to cisterns to be made by means of brass screw union joints, with double nuts. Short pieces of iron pipe, screwed, and with back nuts, will not be allowed to be used.

Large cisterns or tanks.

136. Cisterns holding more than 300 gallons to be of cast iron, *vide* W.O. P.B., Plates 83 to 89, the joints of various sections to be made with a rust cement, composed of 80 per cent. iron filings, 2 per cent. of sulphur, and 1 per cent. sal-ammoniac, in addition to the bolts of the flanges shown in the plates referred to.

137. The large cisterns, or tanks over 300 gallons in capacity, and the material for jointing, will be supplied by the War Department.

Position of cisterns.

138. The whole of the cisterns and tanks are to be fixed approximately where shown on the drawings, or at such other positions as may be directed, in order to give easy access and ample light.

Ball valves.

139. The ball valves to the cisterns to be 1-inch in diameter, high pressure ball valves of the description made by Messrs. Guest & Chrimes, the Glenfield Co., Kilmarnock, with horizontal action, or other approved manufacture.

Cisterns to be protected from frost.

140. Wrought-iron cisterns to be protected from frost by a casing of ¾-inch deal, rebated and ledged, and lined with a layer of silicate of cotton, about 1 inch in thickness and secured thereto by nails. The casing to be made in sections, and kept in position by wrought-iron fittings, as shown in the detail drawings, so that they can be easily removed, if required.

Covers to out-door cisterns and tanks.

141. The covers to out-door cisterns to be 1-inch deal, ploughed, tongued, ledged and braced, with double chamfered fillets over the joints, made in sections, and fitted on a 1½-inch dovetailed frame, fitted to tops of cisterns, and made to slope to one side.

Cisterns in roofs to have safes.

142. All storage cisterns in roofs to be provided with safes. The safes to be of 1-inch deal, wrought, ploughed, and tongued, and with 2-inch by 1-inch rim, to be lined with 5lb. lead dressed over the rim. The wastes from safes to be 1½-inch lead pipe, carried directly into the open air, not being directly over a door or window, or to other approved position, and to be provided with copper flaps. The wastes must not connect with the safes near any valve or pipe.

Sizes of cisterns.

143. The sizes of cisterns will be calculated from the following data :—

I. *Ablution Rooms*—30 gallons per basin and 30 gallons per foot basin.
II. *Baths*—250 gallons per bath, also a hot water cistern for 50 gallons per bath.
III. *Canteen*—½-gallon per head on accommodation for N.C.O.'s and men.
IV. *Coffee Bar to Recreation Room*—½-gallon per head on accommodation for N.C.O.'s and men.
V. *Cook Houses*—3 gallons per head on accommodation for unmarried men.
VI. *Hospital Kitchen*—3 gallons per bed.
VII. *Infection Ward*—25 gallons per bed.
VIII. *Latrines*—20 gallons per compartment.
IX. *Married Men's Quarters*—50 gallons per quarter.
X. *Mortuary*—50 gallons.
XI. *Officers' Mess*—15 gallons per officer.
XII. *Sergeants' Mess*—3 gallons per sergeant.
XIII. *Sinks for Officers' Quarters*—80 gallons per sink.
XIV. *Stables for Saddle Horses*—16 gallons per horse.
XV. *Stables for Draught Horses*—20 gallons per horse.
XVI. *Traps in Yard*—80 gallons each.
XVII. *Urinals*—20 gallons each compartment.
XVIII. *Wash Houses*—60 gallons per trough.
XIX. *Water Closets*—60 gallons each.
XX. *Workshops for Armourer, Carpenter and Plumber*—50 gallons.

144. Cisterns supplying the W.C.'s, urinals and hospital sinks, to be kept distinct. Small feed cisterns, supplied from the general cistern, may be used in connection with W.C.'s.

PROVISIONAL SERVICES.

145. The contractor is to include in his tender for this contract amounts hereinafter named by him for the purposes stated, which are to be considered as charges for the execution of provisional services only, and to which he shall have no claim unless the work therein quoted has been ordered and carried out to the complete satisfaction of the Superintending Officer, in virtue of which a written order for the execution, and a certificate on completion of the work shall be necessary.

(a) Complete record plans of all work executed in this contract (*vide* clause 28). £

(b) Screening gravel for filtering material (*vide* clause 45) …….. £

(c) Labour and material in making test blocks for concrete (*vide* clause 50). £

(d) Insertion of bond stones between concrete layers and difference in cost of material (if any) supplied only (*vide* clause 57). £

(e) Cost of application of tests to iron and steel work other than cast or wrought-iron pipes (*vide* clause 76). £

(f) Connecting War Department main to Water Company's main £

(g) Temporary connections of old to new pipes as directed (*vide* clause 110). £

(g) Fixing only, all cisterns and tanks over 300 gallons in capacity, exclusive of rising main, service (supply and delivery) pipes, all unions or connections, stop or ball valves, material for jointing bolts, wood casing and non-conducting substances, safes, wastes, and necessary supports (*vide* clause 137). £

APPENDIX III.

SPECIFICATION FOR PIPES, MURREE WATER WORKS.

The 6-inch main will be subjected to pressure equal to 650 feet head of water, and the 5-inch main to 1,350 feet head.

Tubes, Bends, and Tees.

The steel of which the tubes are made is to be perfectly free from lamination, buckles, blisters, and all defects of manufacture. It will be subjected to the tests detailed in attached specification of tests.

Notice in writing is to be given to the Superintendent of the Indian Store Depôt when the contractor is ready to have the steel examined and tested at his works. The tested samples are to be forwarded to the Indian Store Depôt free of expense, and no charge is to be made for them. Samples of the tubes and sockets proposed to be supplied are to be forwarded for approval at the same time.

The manufacture of bulk is not to be proceeded with until the Superintendent has approved the above samples in writing.

The tubes and fittings are to be supplied of the lengths, numbers, and sizes detailed in the schedule.

The whole of the tubes and fittings are to be tested at the contractor's works in Great Britain by hydraulic pressure to 6-inch, 1,200 lbs., and 5-inch, 1,800 lbs., per square inch, in the presence of the Superintendent of the India Store Depôt, or his deputy, and any which show any signs of failure will be rejected. The contractor is to provide the necessary apparatus, and carry out the testing at his own expense. The mark M.W.S. is to be stamped on each length, socket, or fitting approved.

After approval, the tubes and fittings are to be thoroughly cleansed from rust and dirt, and coated, while hot, with asphaltum composition.

Drawings of the Tees, showing method of construction, are to be submitted with the tender. Should any of the parts be screwed, the male threads are to be "plus threads," that is, the pipe is to be thickened to receive the thread, so that it shall be in no wise weakened by being screwed.

Cast-iron bifurcating pieces.

To be of the form shown in drawing No. 2,135, with flanges of the dimensions provided for the mains with which they are to be connected, flanges to match those used in making the joints in the steel tubes. The contractor to figure on the drawing the dimensions of the pipes it is proposed to supply. The thickness of the C.I. pipe to be not less than $\frac{3}{4}$ inch. The bifurcating pieces will be tested on the contractor's premises by hydraulic pressure to 1,200 lbs. per square inch, under conditions in clause 5 of the specification applying to tubes, bends, and tees. The letters M.W.S. are, however, to be cast upon them in Roman characters 1-inch long $\frac{1}{16}$-inch projection. After approval they are to be thoroughly cleansed from rust and dirt, and coated, while hot, with asphaltum composition.

Sluice valves.

A sketch or woodcut, showing the valves it is proposed to supply, to *accompany the tender.*

The valves to be best double-faced, with four gun-metal faces, two on body of sluice, and two on valve, gun-metal spindles, and nuts bored out for the stuffing gland, which is to be bushed with brass. The flanged ends to match and be drilled and fitted to the flanges of the mains with which they are to be employed.

The 3-inch valves may have flanges of the usual dimensions, and for this purpose the pair of flanges for the 3-inch branches out of the tees must be adapted to suit them. One side of each 3-inch valve to be completed with a flanged socket (drawing No. 1,045) bolted to it.

The bodies of the valves to have the letters M.W.S. cast on them.

The valves will be tested on the contractor's premises in Great Britain, in the presence of the Superintendent, India Store Depôt, or his deputy, by hydraulic pressure to 1,800 lbs. per square inch.

Air valves.

To be double self-acting, and flanged to suit the mains with which they are to be used. The flanges to match and be fitted to the flanges of the mains. Woodcuts or sketches of the air-valves to *accompany the tender.*

Flanges for 6-inch and 5-inch steel tube.

A drawing showing the 6-inch and 5-inch flanges (full size), with particulars of thickness, number and diameter of bolts, to be submitted with tender. The joints of the half-flanges to be machined to ensure a perfect fit.

The iron used to be of the best quality, grey pig, re-melted in the cupola. The castings to be free from air or sand-holes, cinder, or other defects, and to have the India Government mark cast on the back of each half. The flanges are not to be painted or coated in any way before being inspected. After approval they are to be cleansed from rust and dirt, and coated with asphaltum composition.

Deacon's patent Water Meters.

The meters to be obtained from the Palatine Engineering Company, on whose premises the inspection required below will be made before the meters are forwarded to the contractor's works.

The meters to be of the best materials and workmanship, and suitable for working under a head of 650 feet.

The meters to be provided with flanges to match those of the 6-inch steel tubes, to which they will be fitted.

A full description of the meters to *accompany the tender.* A guarantee to be obtained from the makers that the meters supplied will work efficiently under the head of water to which they will be subjected. This guarantee to be forwarded to the Superintendent India Store Depôt when giving notice that the meters are ready for inspection.

The meters will be again inspected on the premises of the contractor, in order to see that the flanges correctly fit the flanges of the 6-inch main.

I.R. Washers

The washers to be of suitable size and thickness for making efficient joints, and to be of the quality required by the attached specification of India-rubber. Samples will be selected by the Superintendent India Store Depôt, or his deputy, and are to be forwarded by, and at the expense of, the contractor to the India Store Depôt, Belvedere Road, S.E., to be subjected to the tests prescribed in the specification.

Bolts and Nuts

Are to be made in accordance with the attached specification of bolts and nuts, and to be of such lengths that they will show two threads clear when screwed home.

Joints with valves, bifurcating pipes, and meters.

As there will only be the flange of one tube with which to make the joint, it will be necessary to ensure that the flanges of the cast-iron portion are designed to match the loose flanges to ensure a perfect joint being made.

Trial will be made to ascertain that these joints are satisfactory as soon as the contract is sufficiently advanced to afford an opportunity.

Testing

In addition to the tests prescribed above for the steel tubing, etc., five per cent. of the joints of each size will be subjected to the tests laid down for the pipes. This will be done by joining two or more short lengths together and testing them at one time by hydraulic pressure as would be done with one length of piping.

The Superintendent India Store Depôt, or his deputy, will select the pipes to be joined together and the flanges. I.R. washers to make the joints.

Packing, etc. —Tubes, Bends, Tees.

Will be shipped loose, each to have the address and such shipping marks as may be required by the Superintendent India Store Depôt stencilled on them in good oil paint.

Bifurcating Pipes.

To be shipped loose, each to have the address and such shipping marks as may be required by the Superintendent India Store Depôt stencilled on them in good oil paint.

Sluice Valves —Air Valves Flanges.

To be packed in skeleton cases and marked as above.

To be secured in pairs by their own bolts and nuts. Five per cent. to have the address M.W.S., Karachi, stencilled on them in good oil paint.

I.R. Washers and spare bolts & nuts.

To be packed in cases in accordance with the attached specification of packing cases, the bolts and nuts to be packed first in bags according to their sizes, the bags to be marked with the purpose for which the contents are suited, the bags then to be packed in the cases. The I.R. washers to be separated into sizes and similarly packed.

Deacon's Water Meters.

To be packed in cases in accordance with the attached specification of packing cases.

The specification of packing cases governs the marking of stores packed in accordance therewith. Contractor to provide the necessary stencil plates.

Address:—Murree Water Supply, Karachi.

Samples sent to the India Store Depôt, Belvedere Road, Lambeth, S.E., are to be marked "Iron Branch," and are to be advised by a delivery note (form 140) similarly marked.

SPECIFICATION OF INDIA-RUBBER.

All supplies are to be made of the best Para Caoutchouc, and must stand the following tests :—

Dry heat of 270° F. for one hour,
Moist ,, ,, 320° F. ,, three hours,

without impairing their qualities.

The amounts of ingredients other than Para Caoutchouc allowed in the various patterns are shown in the following table:—

Pattern No.	Ingredients.	Amount not to exceed.
342	Sulphur	5 per cent.
3209	Sulphur Antimony	Together 11 per cent.
5370	*Nil.*	*Nil.*
6769	Sulphur White oxide of zinc	3 per cent. 40 ,, ,,
7314	Sulphur White oxide of zinc	3 ,, ,, 70 ,, ,,

None of the supplies are to contain re-manufactured material.

All sheets above ¼-inch thick to be "press-curved."

All samples sent to the India Store Depôt, Belvedere Road, Lambeth, S.E., are to be marked "Leather Branch," and those furnished *after* the acceptance are to be advised by a delivery note (form 140) similarly marked; when delivery of bulk at depôt is ordered, a similar delivery note is to be furnished for each consignment. When samples are required *at the time of tendering*, the Superintendent India Store Depôt is to be advised of their despatch on form 153, a copy of which is, *in such cases*, attached to the invitation to tender.

The washer to be moulded.

SPECIFICATION OF BOLTS AND NUTS.

The iron used for the bolts and nuts is to be free from laminations or other defects of manufacture, and must be of such strength and quality that it shall be equal to the ultimate tensile strains per square inch of original section, and contractions of area at the point of fracture, stated below, viz. :—

Round iron, not less than 24 tons and 40 per cent. contraction.
Flat ,, ,, ,, ,, 23 ,, ,, 30 ,, ,, ,,

It must also stand the forge tests in use at the India Store Depôt, Patterns Nos. 2846, and 2842 (ram's horn and punching).

(2). The bolts are to be made out of rods, the heads being concentric and forged out of the solid.

(3). The bolts before screwing are to stand the following tests :—

(a). Bending hot and cold without fracture through an angle of 180°.

(b). Flattening of the head while hot without cracking at the edges. The head to be flattened until its diameter is two and a-half times that of the shank.

(c). The shank is to be nicked on one side and bent over to show the quality of the iron.

Notice in writing is to be given to the Superintendent, India Store Depôt, when the iron is ready for examination, and also when the nuts and bolts are manufactured.

Three sample bolts (in the black, before screwing) of each diameter are to be forwarded to the Superintendent, India Store Depôt, for approval before the manufacture of bulk is proceeded with. One complete sample of each size is also to be forwarded to the depôt after screwing.

All samples sent to India Store Depôt are to be marked "Iron Branch," and to be advised by a delivery note (form 140) similarly marked.

APPENDIX IV.

Memorandum on the Use of Hydraulic Lime Mortar.*

To the majority of observers the most striking differences between the behaviour of natural hydraulic lime and Portland cement have been:—

I. That Portland cement, being much quicker in setting to a sufficient extent, to resist the erosive action of running water, is much more suitable than hydraulic lime for subaqueous work.

II. That, judging from the comparatively few published tests of the strength of hydraulic lime, that material exhibits a most remarkable irregularity of quality, whereas Portland cement may always be obtained with a minimum strength much higher than has hitherto been supposed to be possible with hydraulic lime.

The idea that nothing but Portland cement should be used in connection with waterworks has been accepted very largely, but the results of recent experiments go to prove that it is possible, by proper manipulation, to use hydraulic lime with perfect success in very many of the works involved in a water supply project, and thus to render possible work, which, if built entirely of cement, would be of prohibitive cost.

That it is possible to use hydraulic lime, as commonly manipulated, was well illustrated by the very numerous tests published by Mr. W. J. B. Clerke, in his paper on the Tansa Dam (*Minutes of the Proceedings of the Institution of Civil Engineers*, Vol. CXV.). Mr. Clerke's results referred to the compressive strength of the mortar. They are somewhat variable, but give average strengths of 774lbs. per square inch in samples from 6 to 11 months old, 982lbs. from 12 to 23 months, and 1,461lbs. above that age.

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* This memorandum has been based on a communication from Mr. G. F. Deacon, M.Inst.C.E. It deals with matters which are of peculiar importance to R.E. officers, whose duties frequently take them to parts of the world where Portland Cement is unobtainable, save at a ruinous price. Mr. Deacon's communication embodies observations and extensive experiments, which are not yet complete, and the ultimate publication and classification of his results is awaited, but he has kindly allowed the writer to publish the following statement in this work.

The mortar was composed of 1 part by measure of slaked lime to 1½ parts by measure of hard sand. The bulk of the mortar was mixed in four-pan mills, driven by steam power. Some of it was mixed in the ordinary mortar mills used in India, viz., circular troughs of masonry, in which edge stones were made to revolve, the motive power being furnished by oxen. The results of tests made during the operations show that the mortar mixed in the steam pans was the better of the two.

There are many old examples of hydraulic limework which are, to all appearances, as good as if they had been constructed with Portland cement. The history of the manufacture of Portland cement, too, indicates that no improvements have been made in the strength and uniformity of that material, which do not bring its behaviour, while setting, somewhat nearer to that of hydraulic lime. Rich, or *fat* lime, as it is called, when mixed with *puzzuolana*, a silicate of alumina, as used in Italy, or *surkhi*, as used in India, has given excellent results when properly treated.

The puzzuolana or surkhi is merely mixed mechanically with the lime, and at the surface of the grains a chemical union certainly occurs ; but a perfect mechanical mixture of materials must be secured before complete chemical union can be attained. The ancient Romans seem to have crushed the puzzuolana in some cases, and the mortar then does not exhibit the spots of pink puzzuolana, so common in modern Italian mortar. But although the Italian architects have written learnedly about such combinations, and have, with Vicat's needle, been in the habit of testing the strength of their mortars, they do not anywhere, so far as Mr. Deacon has ascertained, pass both the lime and puzzuolana through a crushing mill, as is necessary to produce complete mechanical mixture and chemical union.

Experiments, however, have shown that the strength of the mortar was always more than doubled when this precaution had been taken. The sand used should, of course, be added after the mechanical incorporation of the lime with the silica and alumina has been completed.

Mr. Deacon's experiments were begun by him because he had found that hydraulic lime, as usually manipulated, did not uniformly combine. These experiments include mortar made from different limes and different kinds of crushed rocks used as sand.

Any hard rock, newly crushed, is superior to the best natural sand as a material for either cement or lime mortar. This has been proved by experiment without a doubt.

The materials were at first manipulated by hand, but it soon became obvious that no slaking and hand-mixing, however thoroughly performed, secured the uniformity of strength desired. A small mill was, therefore, constructed, producing the same effect upon the lime as that of well-made edge runners (in which the runners touch the pan throughout their width in every position, or nearly so, as they would do perfectly if the runners were turned and the pan planed or turned to a plane).

Except those experiments already referred to concerning puzzuolana and lime, the experiments of Mr. Deacon were made with lime of the lias formation, known in the trade as blue lias. The sands used were all crushed from rocks, chiefly by percussive action, to such a size that the whole would pass through meshes $\frac{1}{10}$-inch square in the clear.

The materials were made into stiff mortar, the lime being manipulated in a variety of ways, and the different mortars were rammed into tension moulds with 1-inch square necks, and compression moulds 3 inches diameter and 3 inches deep. While in the moulds these briquettes were kept under damp cloths, and when strong enough to be removed they were placed under water and tested after 2, 4, 6 and 12 months; a fifth briquette of each batch being kept for a longer period.

Broadly speaking, the results obtained are as follows:—

I. When the lime is slaked—but not subsequently, or at the same time, ground—there are invariably certain unslaked refractory particles still remaining. The mortar after 6 months (owing to the subsequent slaking of these particles) deteriorates in strength to a very serious extent, and this is the case whether the lime is, or is not, ground before being slaked.

II. When the lime is slaked and then ground in a plastic condition, so that the number of refractory particles is largely reduced, greater thoroughness and uniformity of slaking is produced, and the result is uniformity of strength in the 4th and 6th months, and then a considerable increase of strength up to the 12th month, and possibly afterwards.

III. When the slaked lime is sieved and the refractory unslaked portions are thus separated, they may, after grinding, be readily slaked. Mortar made from these portions gives higher results than from those which were readily slaked in the first instance, and, therefore, passed through the sieve without grinding.

IV. The more complete the grinding of the refractory particles the better is the ultimate result.

V. Lime when slaked and pounded with a pestle before being made into mortar gave excellent results. If kept for some time before being mixed with the sand, the ultimate result was improved, though there are indications that a slight prolongation of the grinding without subsequent keeping is better still.

Mortar 2·5 of sand to 1 of plastic hydrate of lime ground five times for a quarter of an hour each time gave a tensile strength after 6 months of 161lbs., and after 12 months of 320lbs. per square inch, with a compressive strength of 1,774lbs. and 2,892lbs. per square inch respectively. These figures are expressed in lbs. per square inch so as to be comparable with Mr. Clerke's results above alluded to, in which, however, the proportions were 1½ to 1 instead of 2·5 to 1, as in Mr. Deacon's experiments.

Here it may be advisable to note the difference that obtains between the ordinary custom of measurement in England and in India. In England 1 part of lime means 1 part in the ground, unslaked condition, a common commercial form. Indian engineers, however, in speaking of 1 part of lime in connection with a mortar mean hydrate of lime, that is to say, the lime after slaking. Now 1 volume of ground hydraulic lime gives about 1·45 volumes of lime slaked into a plastic condition, so that, in order to compare with the condition in which lime is sold, we must call Mr. Deacon's proportions 3·6 sand to 1 of ground lime, and Mr. Clerke's 2·16 to 1. Moreover, as Portland cement is about 17 per cent. heavier than ground lime, the same weight of lime goes 17 per cent. further.

VI. When ground for an hour, then mixed with sand, then returned to a mill with a pestle so arranged as to produce a kneading action instead of a grinding action, the results were very good. In some cases mortar 3½ to 1 gave, after 2 months, 103lbs. in tension, and 635lbs. in compression, and after 6 months 245lbs. in tension, and 2,660lbs. in compression.

The experiments show conclusively that if the best results are to be obtained with such limes, the refractory particles must in some way be reduced before the mortar is placed *in situ*, and that when they are so reduced the strength of mortar made from these limes falls little below that made from good Portland cement, and the same proportion of sand. Moreover, the lime mortars are much more plastic than cement mortars, and *cæteris paribus* produce better work.

What is wanted to produce the best results is a mill that will automatically and continuously discharge the hydrate of lime as fast as it is reduced to a hydrate. The work may be done under good edge-runners, but here there is no continuous discharge, and some form of rolling mill may possibly prove better. It follows, therefore, that with due care in manipulation, hydraulic lime mortar has yet a great field of usefulness in waterworks engineering, provided it is possible to keep running water away from it during the first few months. So well satisfied is Mr. Deacon with the results of his researches, that even in England he is using hydraulic lime mortar instead of Portland cement in the construction of two masonry dams.

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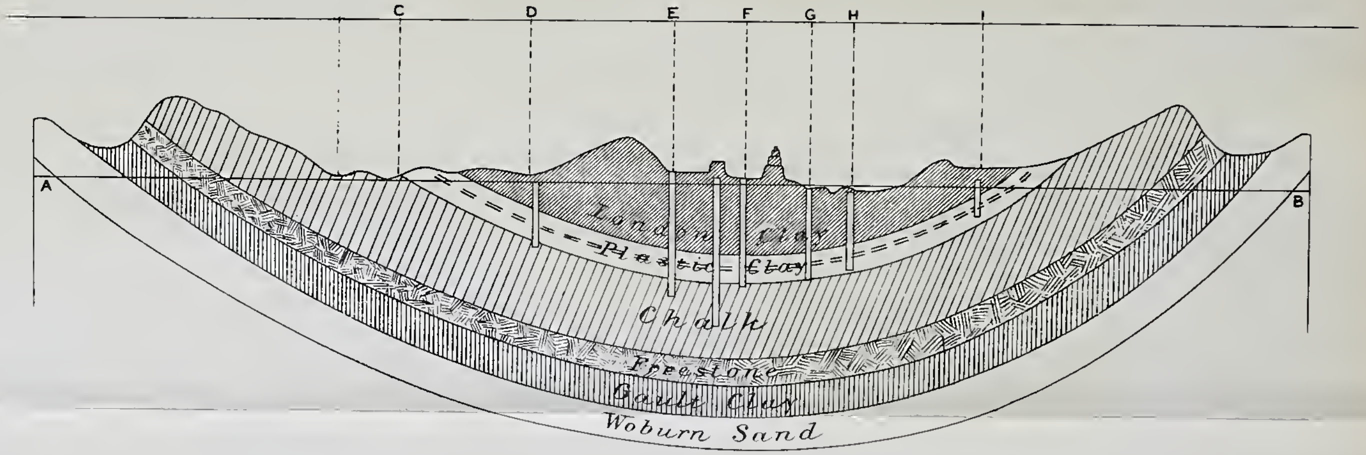
PLATE I.



Section shewing the cause of the rise of water in Artesian Wells in a typical basin resembling that of Paris.

A
A
A
“
“
“
C
E
F
L
Q
R
R
R
T
T
T
T
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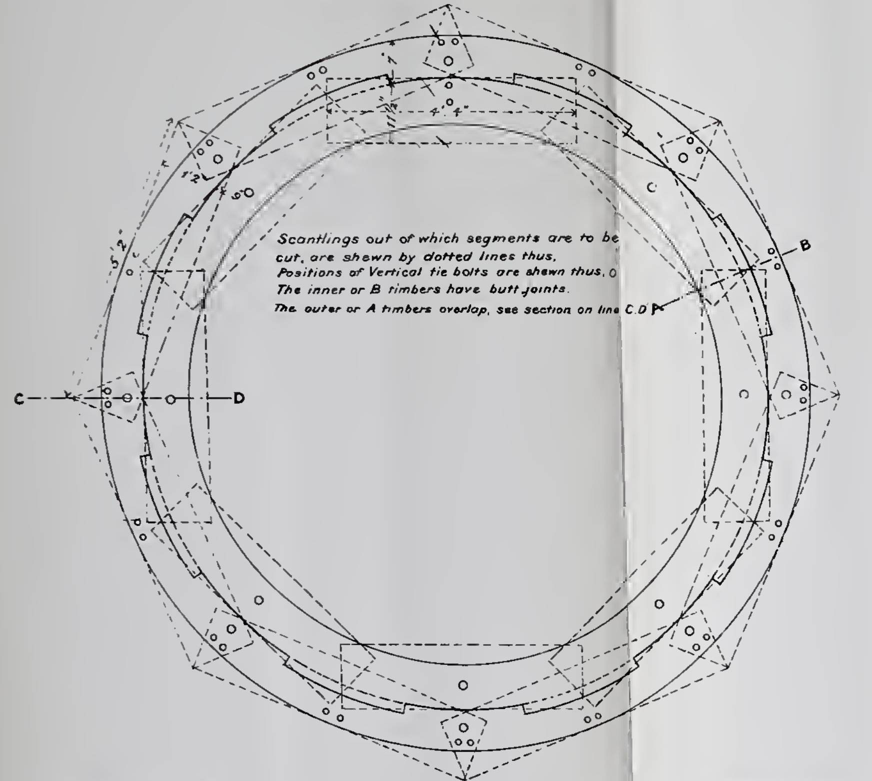
26 JUN. 1929

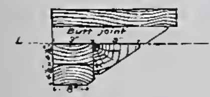
COMBINED IRON & TIMBER CURBS FOR 12 FT 6 IN WELLS.

PLAN OF UPPER SIDE OF LOWER SEGMENTS OF TIMBER ON LINE L.S.

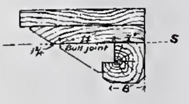


Scantlings out of which segments are to be cut, are shewn by dotted lines thus,
Positions of Vertical tie bolts are shewn thus, ○
The inner or B timbers have butt joints.
The outer or A timbers overlap, see section on line C.D.

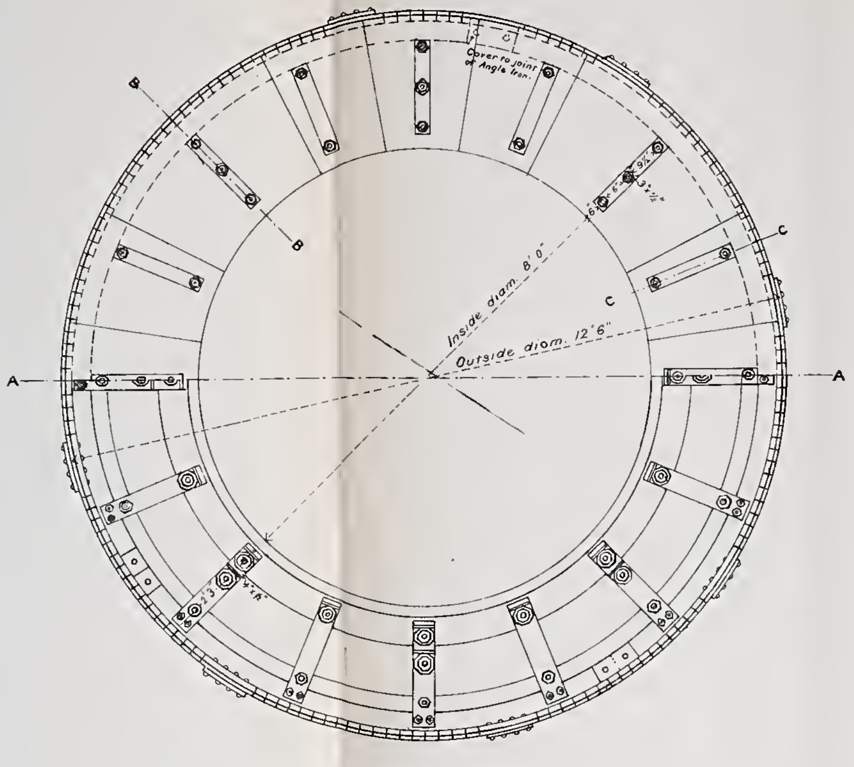
Section on line C D.



Section on line A B.

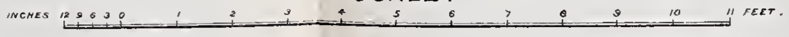


HALF PLAN OF TOP.

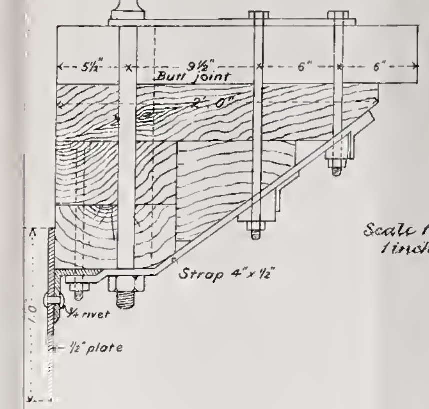


HALF PLAN OF TOP INVERTED.

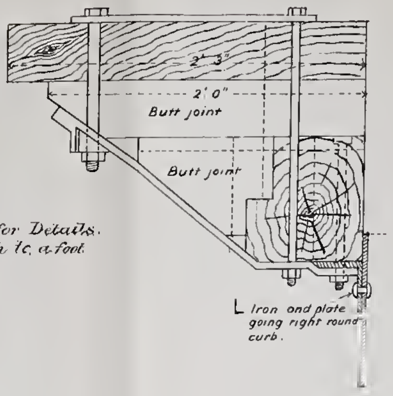
SCALE.



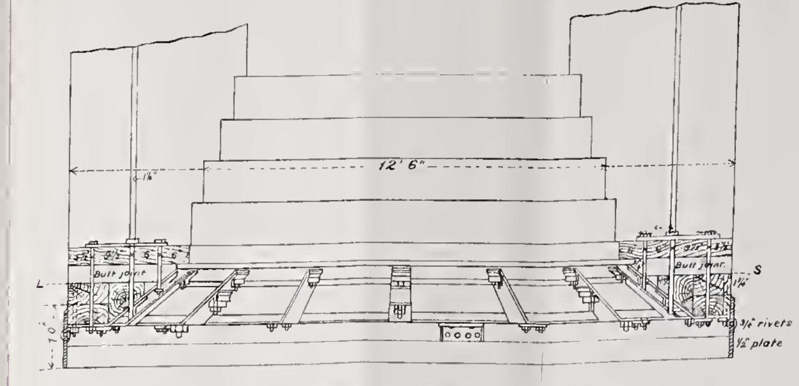
SECTION ON LINE B.B.



SECTION ON LINE C.C.



Scale for Details. 1 inch to a foot.



SECTION ON LINE A.A.

A
A
A
"
"
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V
V
V

WELLS.

PLATE III.

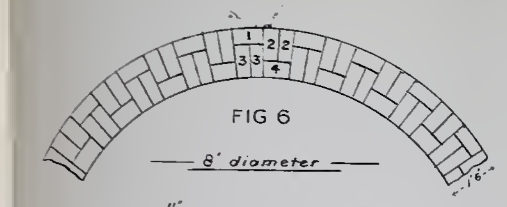


FIG 6

8' diameter

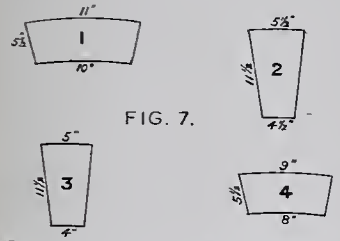


FIG. 7.

Bricks may be laid as shewn or in alternate courses of Nos. 1 and 3, and 2 & 4.

No. of bricks required in one course for whole ring
No 1 ...... 18. No 3 ...... 36.
" 2 ...... 36. " 4 ...... 18.

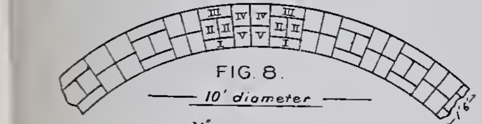


FIG. 8.

10' diameter

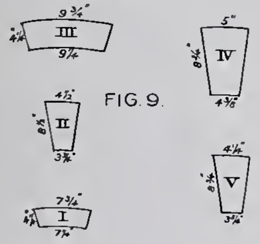
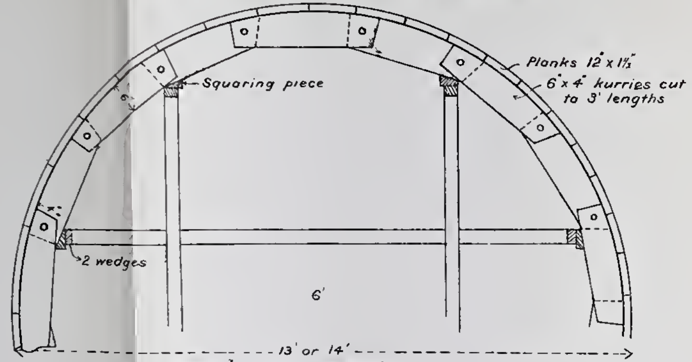


FIG. 9.

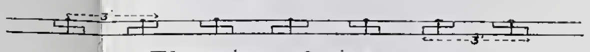
Bricks may be laid as shewn or in alternate courses of Nos. 3, 2 & 1, and 4 & 5.

No. of bricks required in two courses for whole ring i.e. if laid in two alternate courses.
No I ...... 40. No IV 80
" II ...... 80 " V ...... 80.
" III ...... 40.

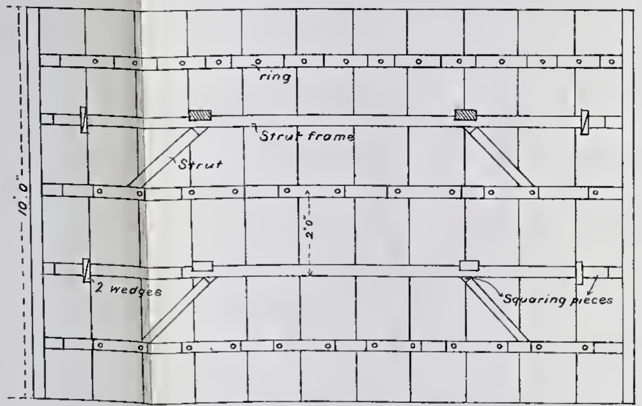
SHORING FOR 8' DIAMETER WELL.



Hor.l Half Section.
FIG. 3.



Elevation of ring.
FIG 4.

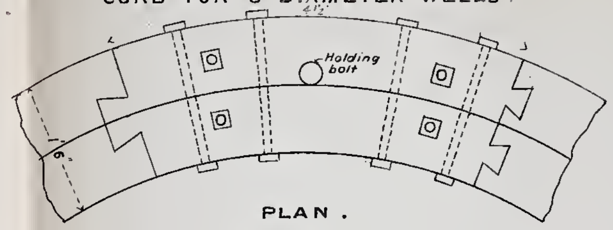


Vert.l Half Section.

To break joint each course must be laid half the width of a header brick further round the circle than the course below.

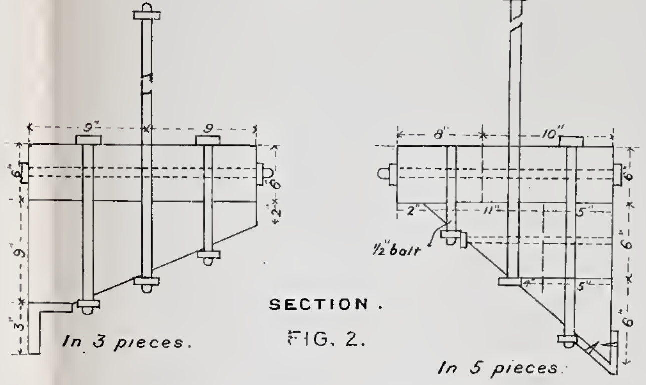
FIG. 5.

CURB FOR 8' DIAMETER WELLS.



PLAN.

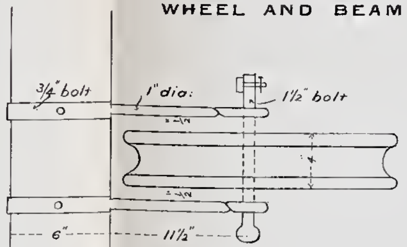
FIG. 1.



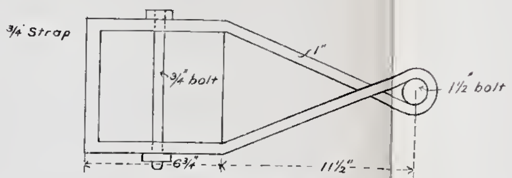
SECTION.

FIG. 2.

WHEEL AND BEAM FOR CHURSA.



Side Elevation.
FIG 10.



Section of Beam.
FIG. 11.

Section of Wheel.

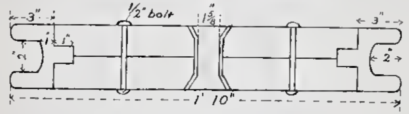
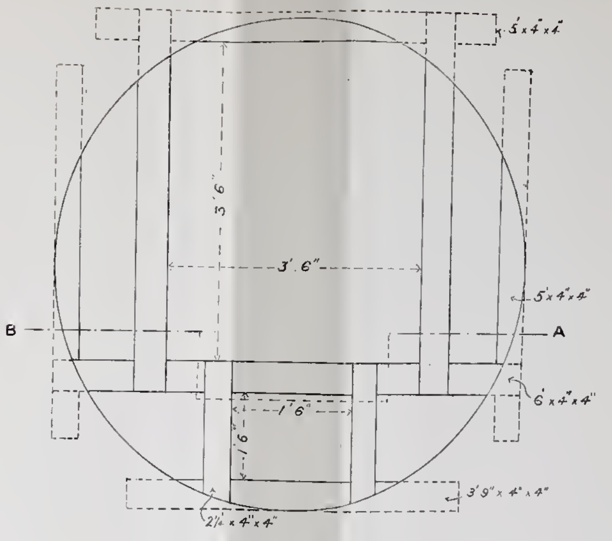
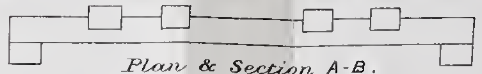


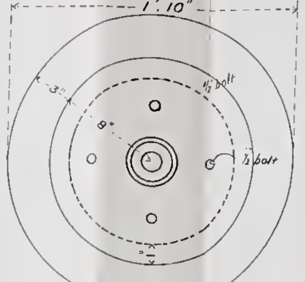
FIG. 12.



6' DIA: WELL COVER FOR 8' DIA: WELL

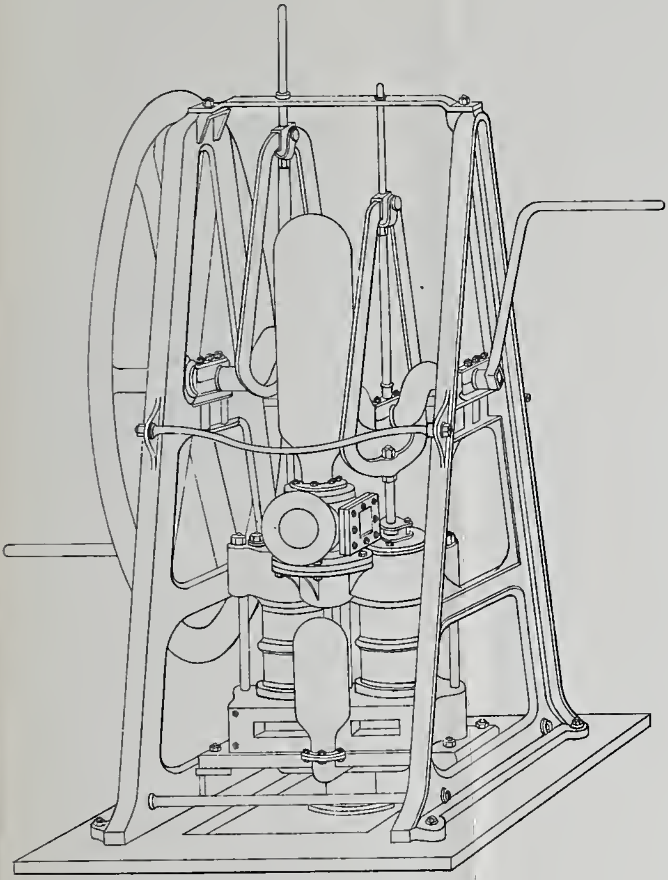


Plan & Section A-B.
FIG. 14.



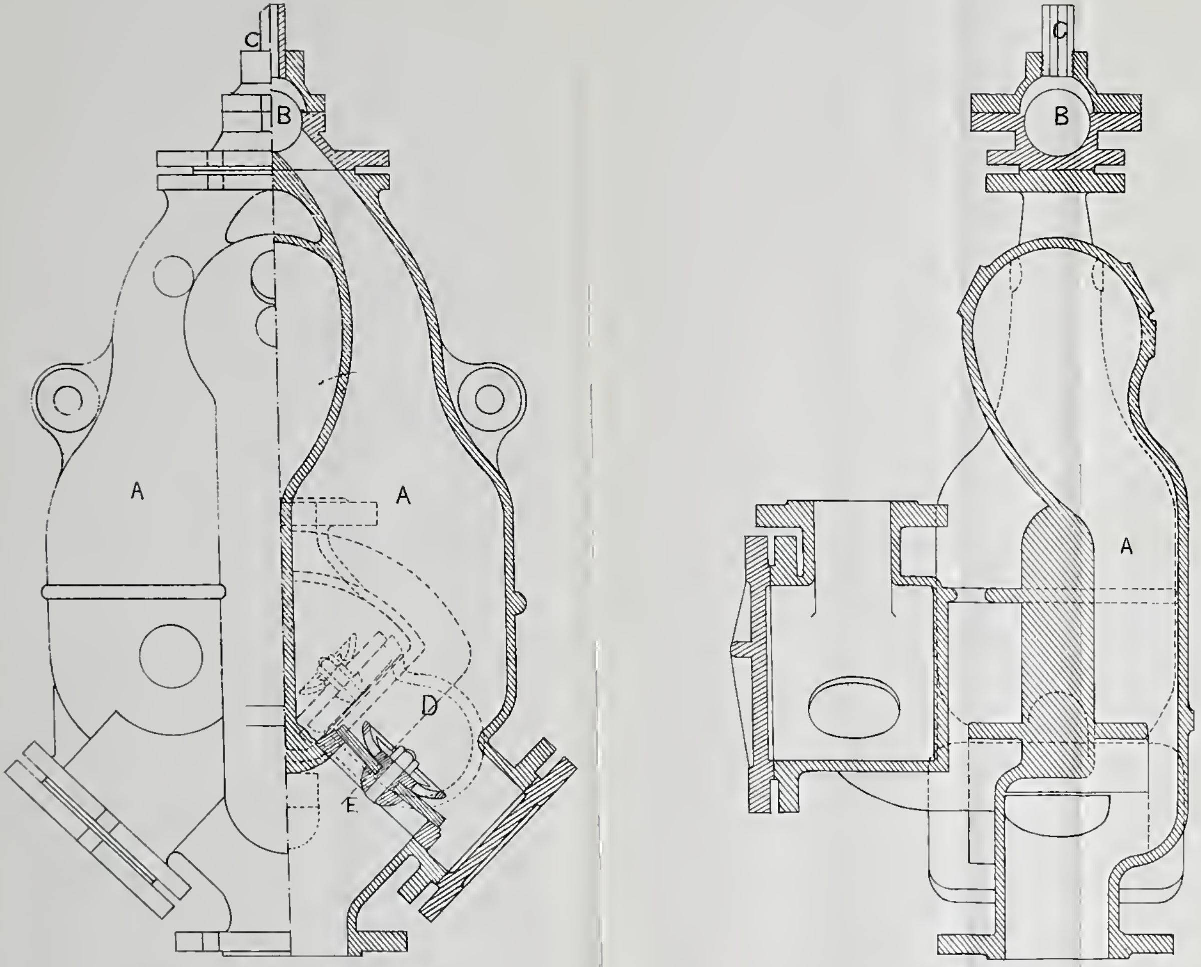
Elevation of wheel.
FIG. 13

DOUBLE-BARREL LIFT & FORCE PUMP.



PULSOMETER STEAM PUMP.

PLATE V.



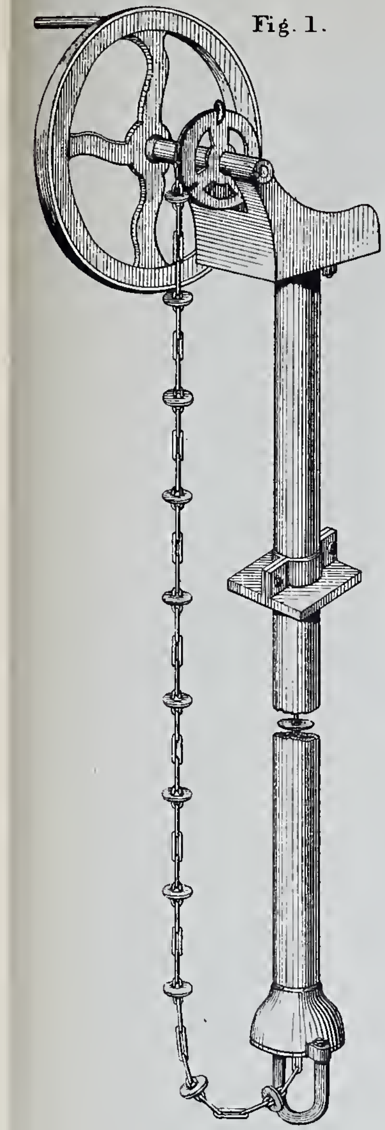
HALF ELEVATION. HALF SECTION.

SECTION.

PLATE VI.

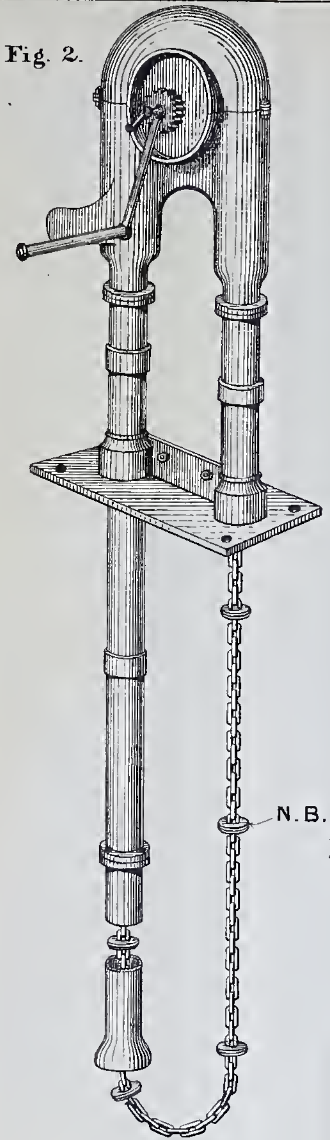
OPEN CHAIN PUMP.

Fig. 1.



COVERED CHAIN PUMP.

Fig. 2.



N.B. *These should be furnished with leather washers to fit accurately the interior of the bore of the rising pipe.*

PLATE VII.

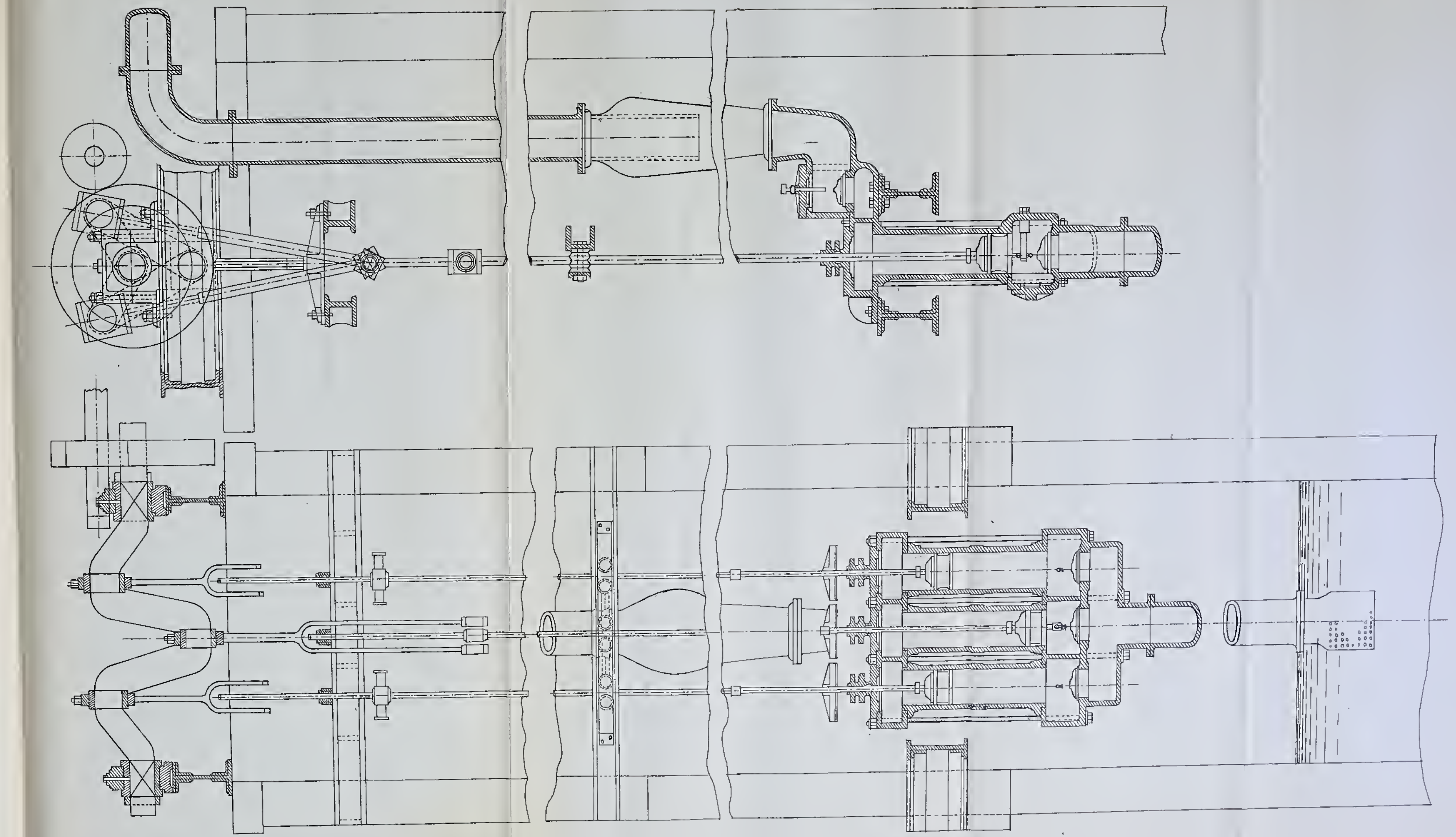
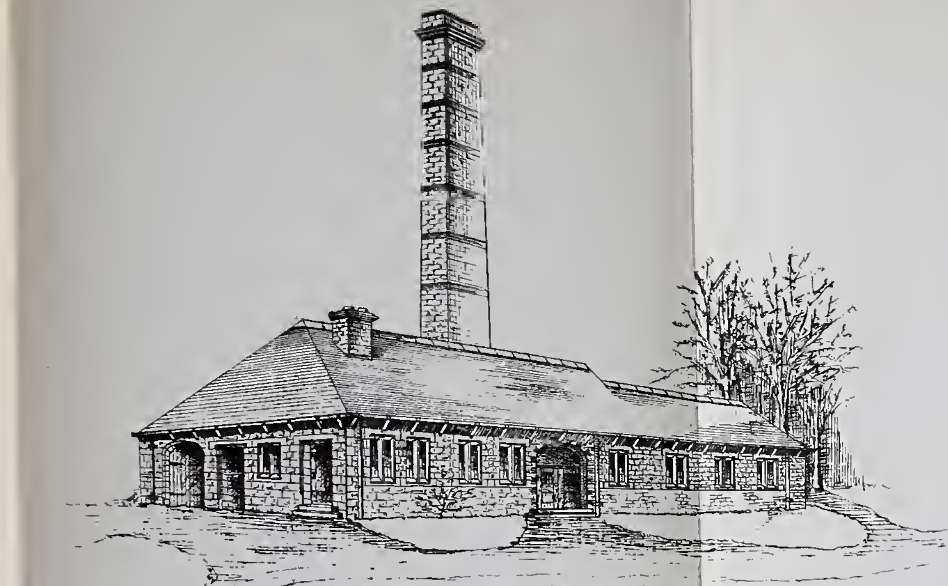
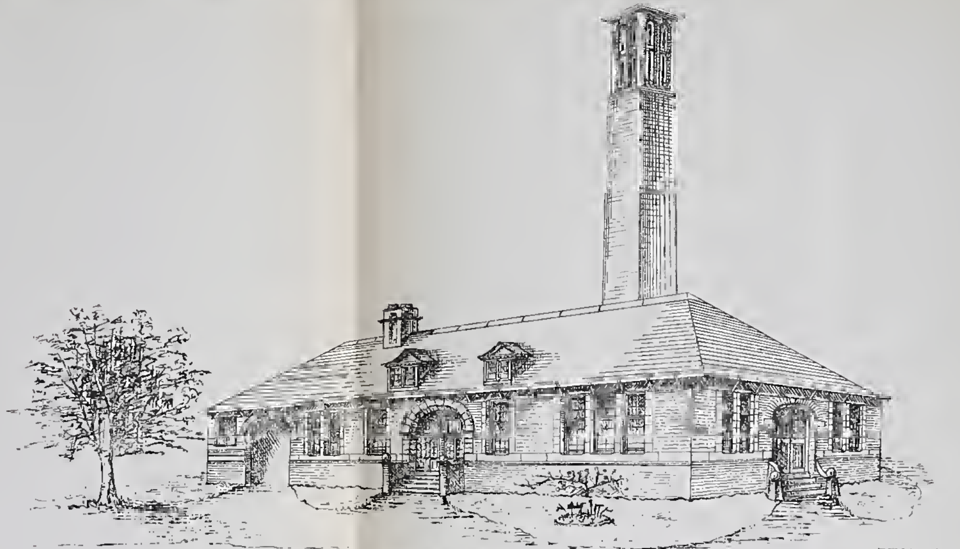


PLATE VIII.

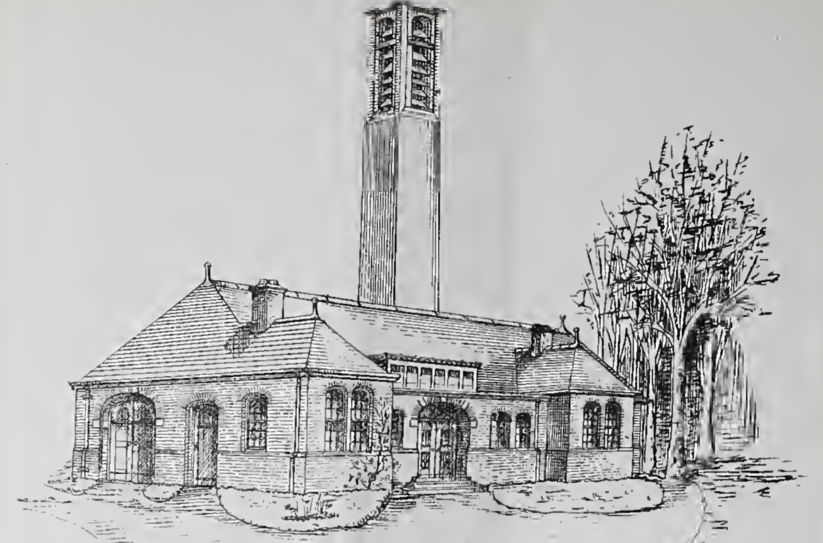
ALTERNATIVE DESIGNS FOR PUMPING STATIONS.



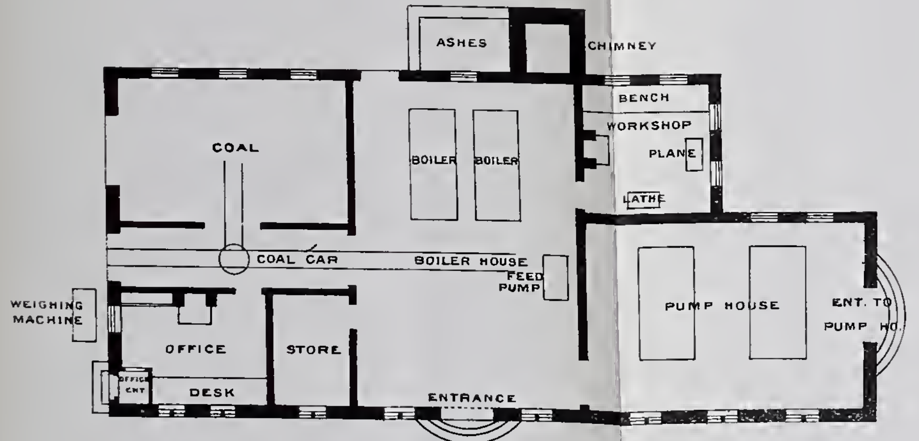
SKETCH No 1. (STONE)



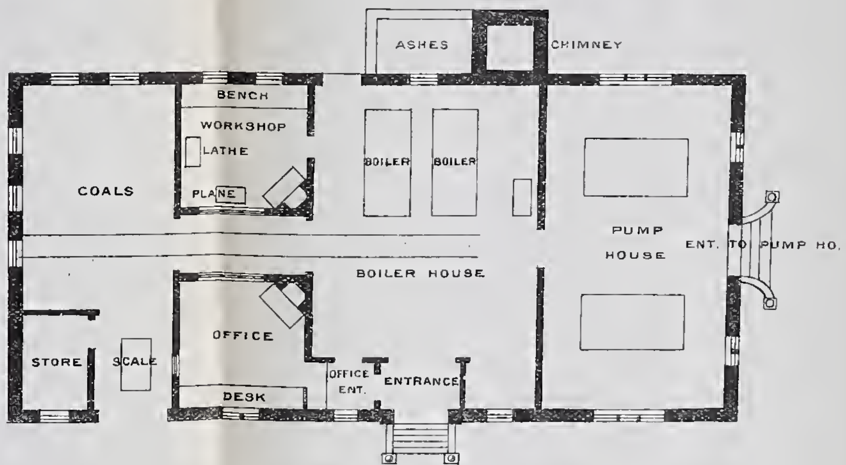
SKETCH No 2. (BRICK & STONE)



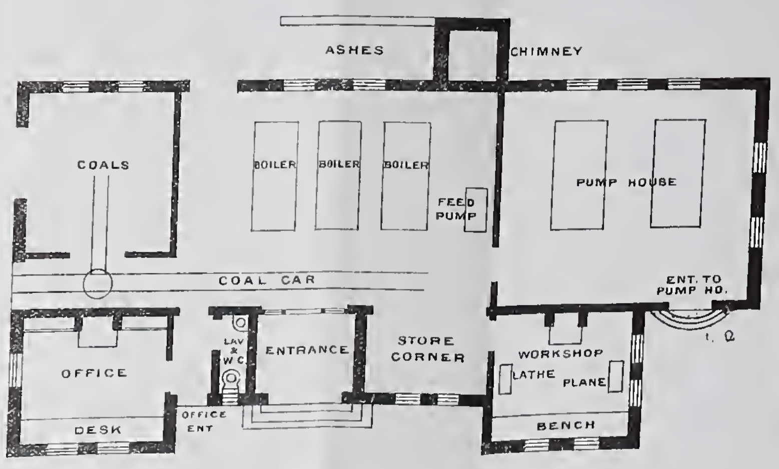
SKETCH No 3. (BRICK)



PLAN No 1.

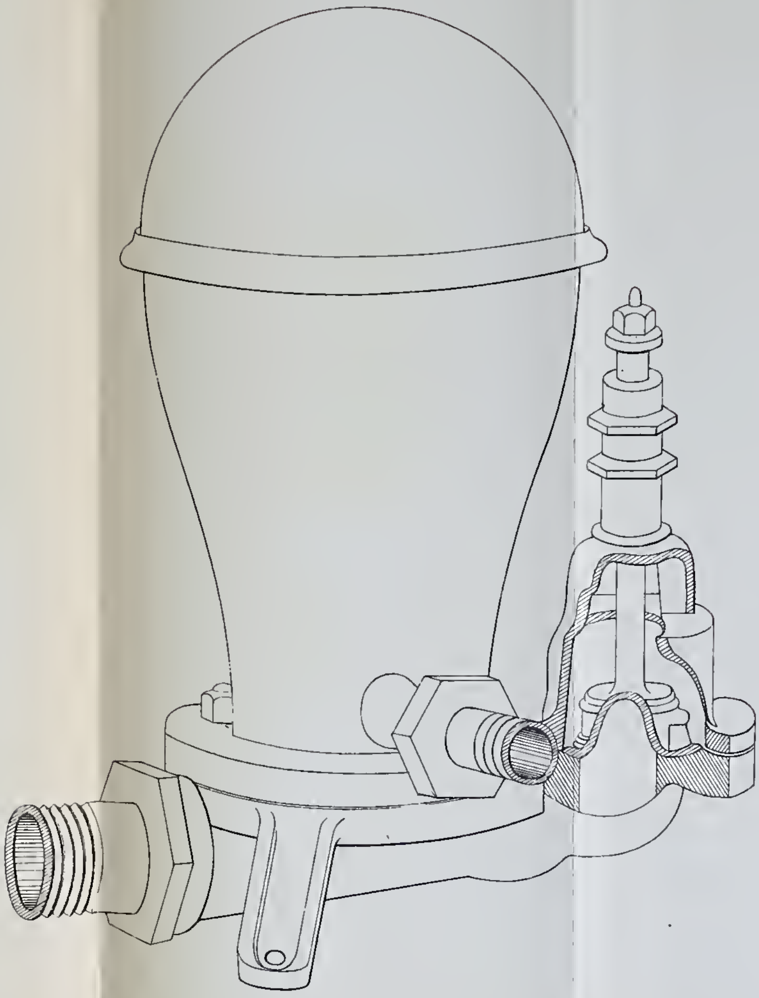


PLAN No 2.



PLAN No 3.

HYDRAULIC RAM.

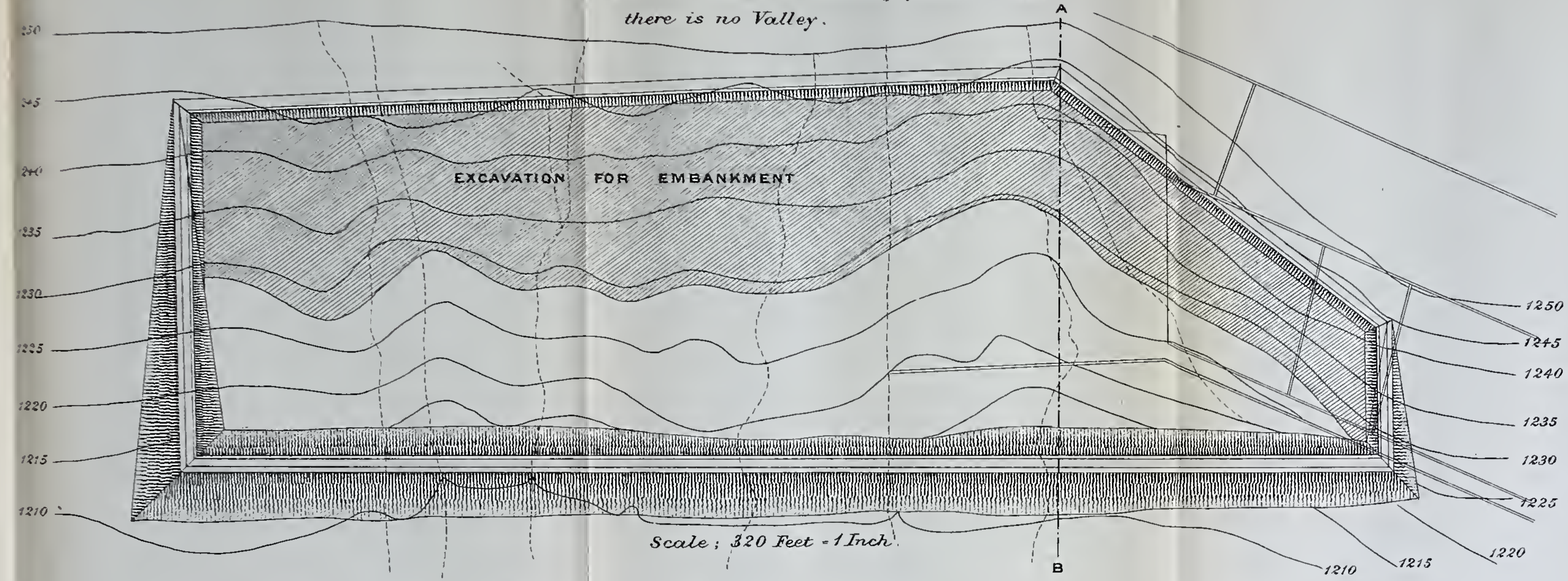


1899

PLATE X.

Fig. 1.

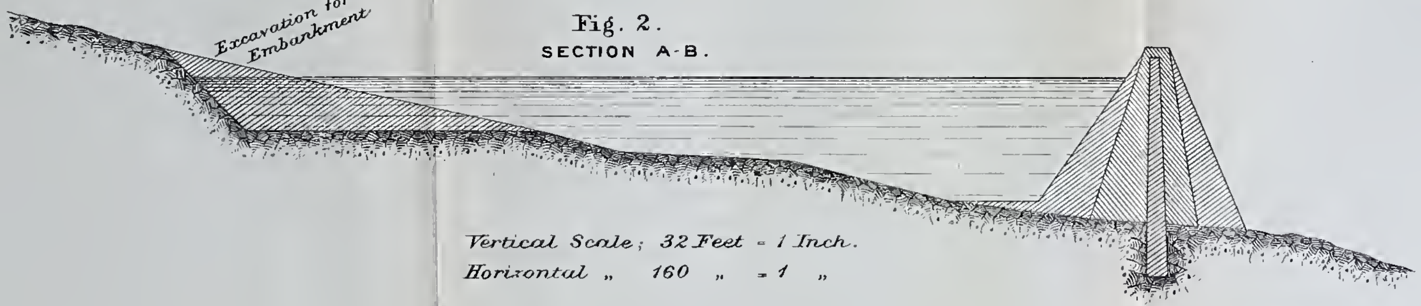
Instance of a Reservoir formed on sloping ground where there is no Valley.



Scale; 320 Feet = 1 Inch.

Fig. 2.

SECTION A-B.



Vertical Scale; 32 Feet = 1 Inch.
Horizontal „ 160 „ = 1 „

Fig. 3.

Site requiring 1 Dam.

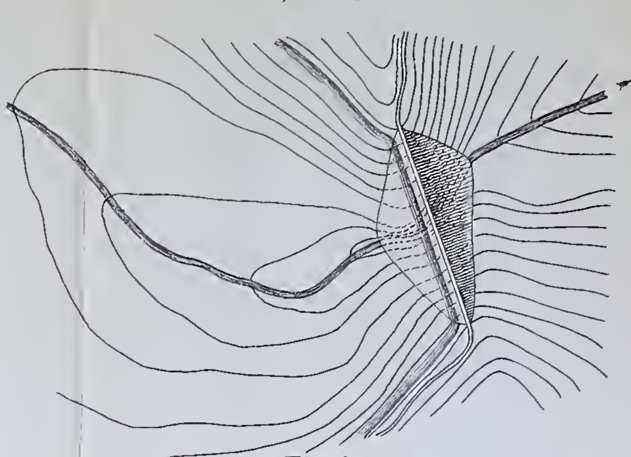
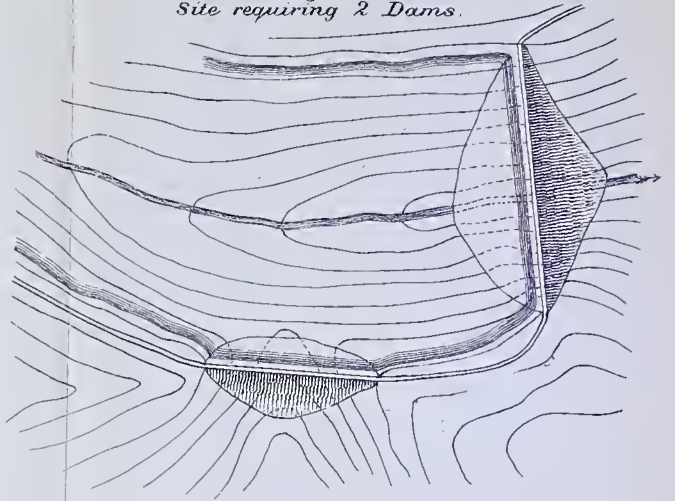


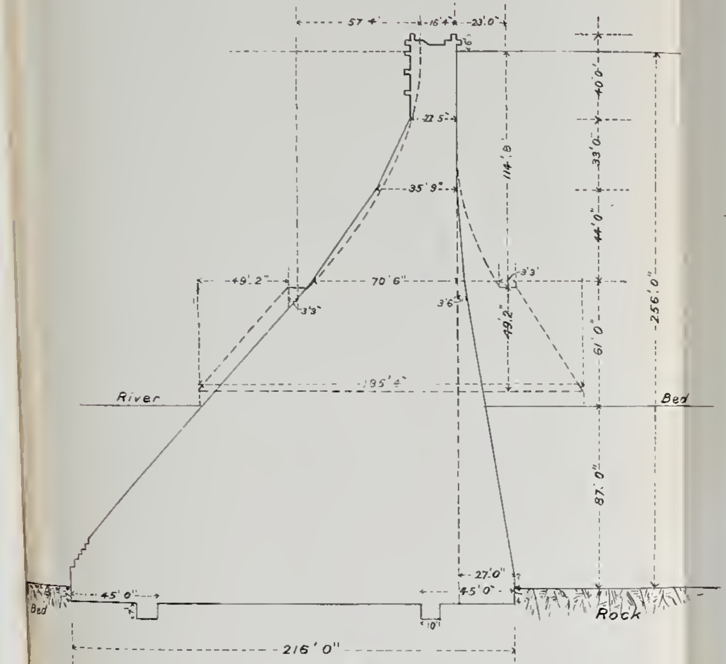
Fig. 4.

Site requiring 2 Dams.

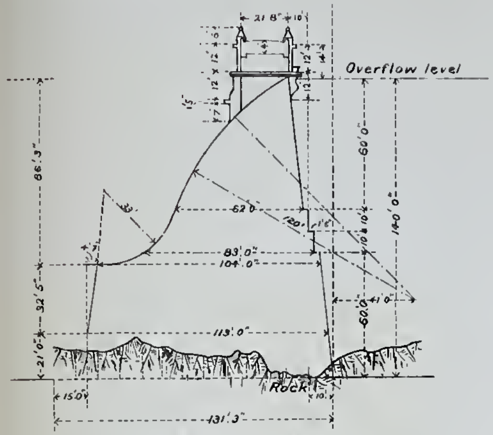


TYPES OF DAMS.

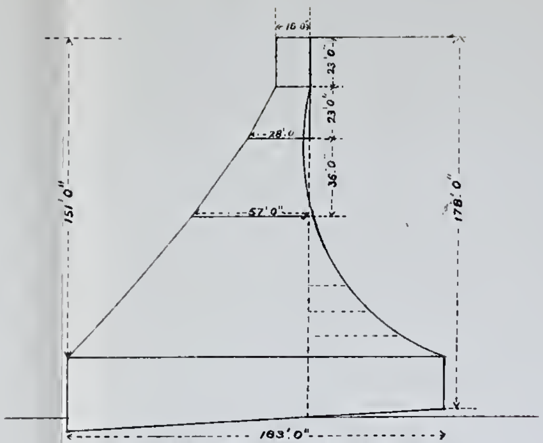
PLATE XI.



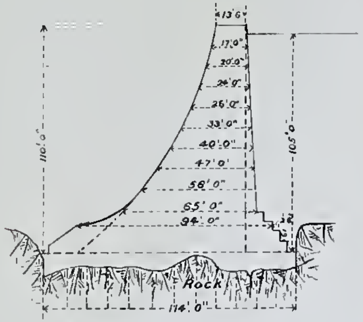
QUAKER BRIDGE DAM.



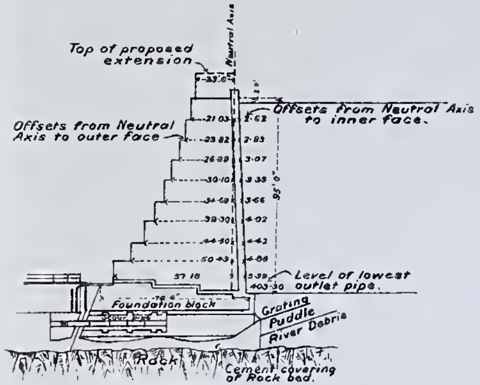
VYRNWY DAM.



PROFESSOR KREUTERS DAM.



BEETALOO DAM.



Top of proposed extension
Neutral Axis
Offsets from Neutral Axis to inner face.
Offsets from Neutral Axis to outer face
21 03
23 82
26 88
30 10
34 58
38 30
44 50
50 43
57 18
1.62
2.93
3.07
3.33
3.66
4.02
4.42
4.88
5.39
403.30
95' 0"
Level of lowest outlet pipe.
Foundation block
Grating
Puddle
River Debris
Rock
Cement covering of Rock bed.

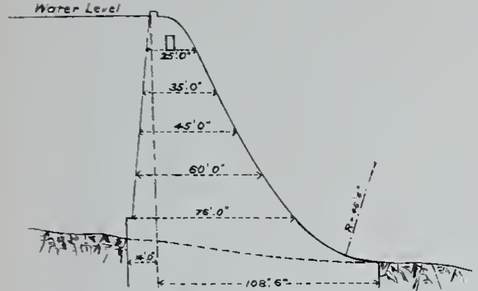
TYTAM DAM.

Scale 80 Feet = 1 Inch.

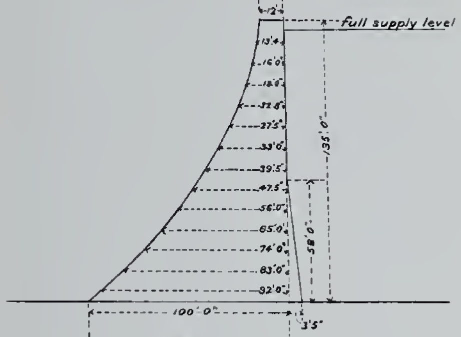
FEET 20 10 0 10 20 30 40 50 100 200 300 FEET

TYPES OF DAMS.

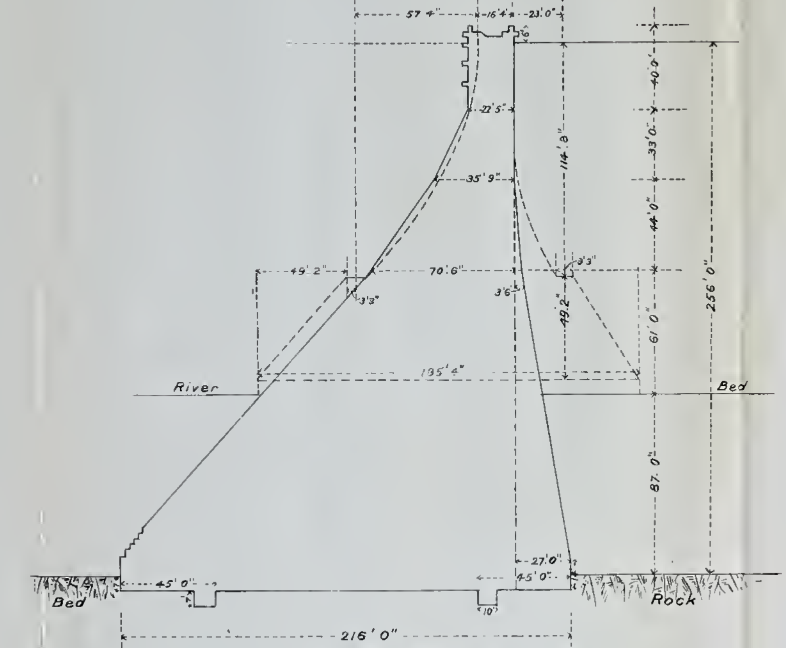
PLATE XI.



CABAN COCH DAM.



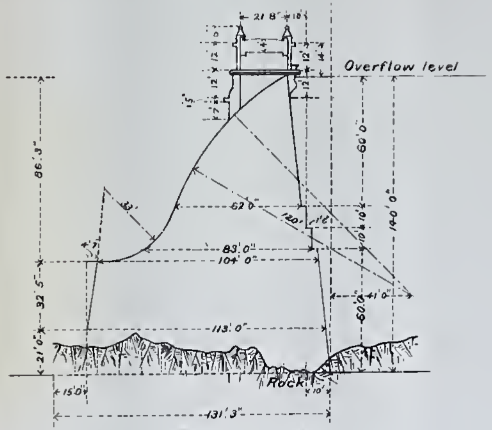
TANSA DAM.



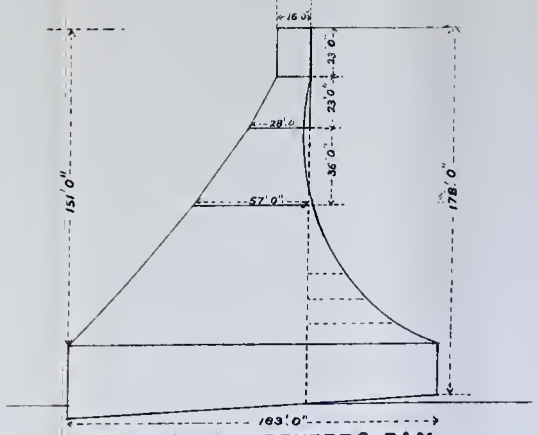
QUAKER BRIDGE DAM.

Scale 80 Feet - 1 Inch.

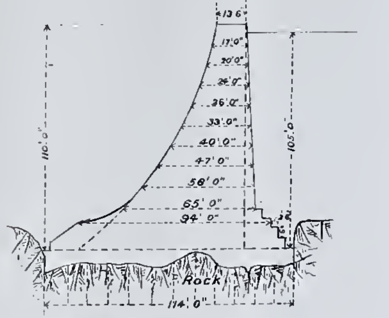
FEET 20 15 10 5 0 10 20 30 40 50 100 200 300 FEET



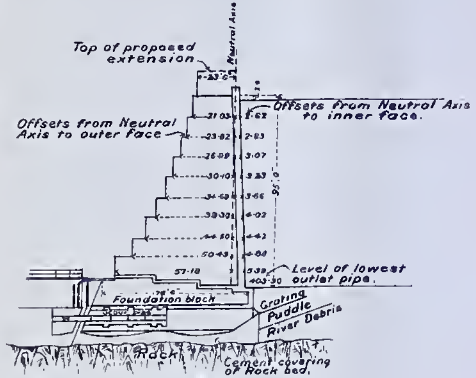
VYRNWY DAM.



PROFESSOR KREUTERS DAM.



BEETALOO DAM.



Top of proposed extension
Neutral Axis
Offsets from Neutral Axis to outer face
Offsets from Neutral Axis to inner face.
Level of lowest outlet pipe.
Foundation block
Grating
Puddle
River Debris
Rock
Cement covering of Rock bed.

TYTAM DAM.

SPECIMENS OF BOTTOMS OF PUDDLE TRENCHES.

Fig. 1.
IN OPEN CUTTING.

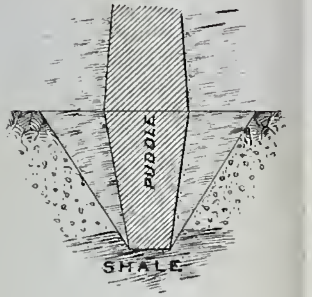


Fig. 2.
BRICK IN CEMENT BOTTOM.

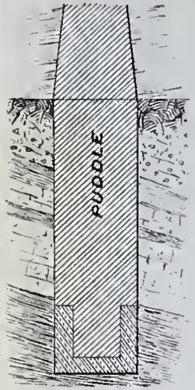


Fig. 3.
HALF CONCRETE BOTTOM.

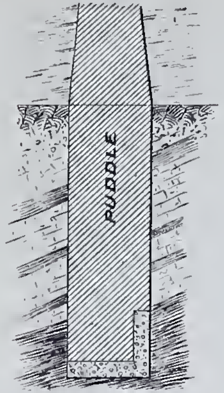
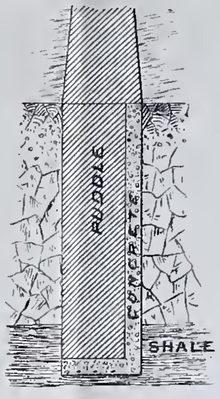


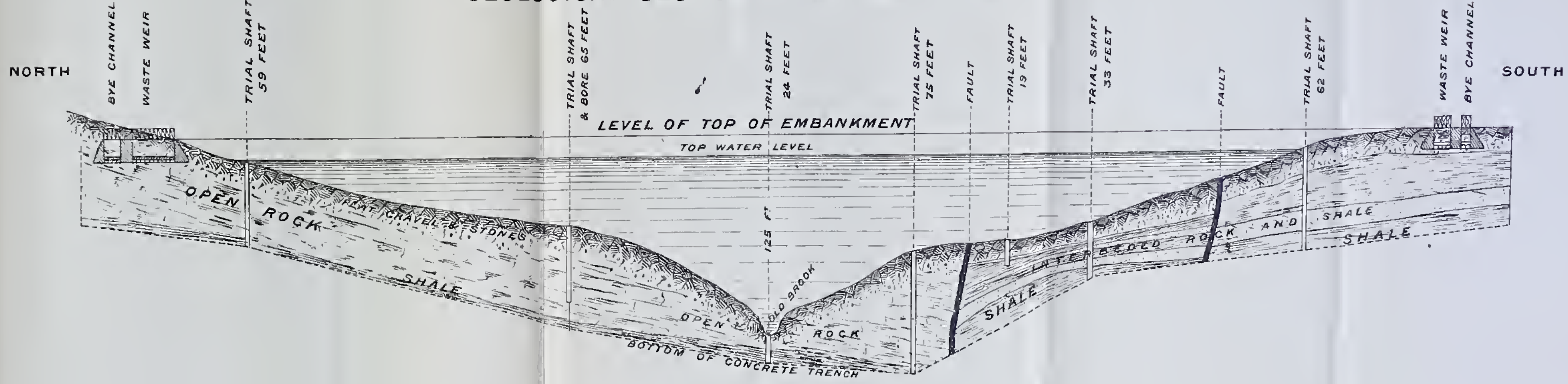
Fig. 4.
LOWER SIDE IN ROCK LINED WITH CONCRETE



Scale; 25 Feet = 1 Inch.

Fig. 5.

GEOLOGICAL SECTION OF PUDDLE TRENCH.

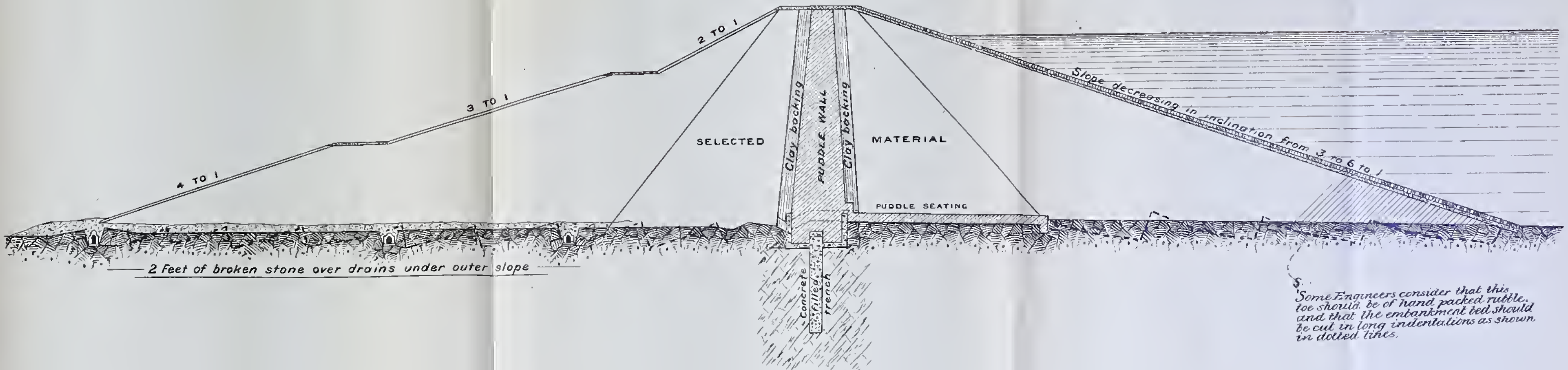


Horizontal Scale; 180 Feet = 1 Inch.
Vertical " : 90 " = 1 " .

PLATE XIII.

GENERAL CROSS SECTION FOR VERY HIGH EMBANKMENT.

Scale ; 60 Feet = 1 Inch.

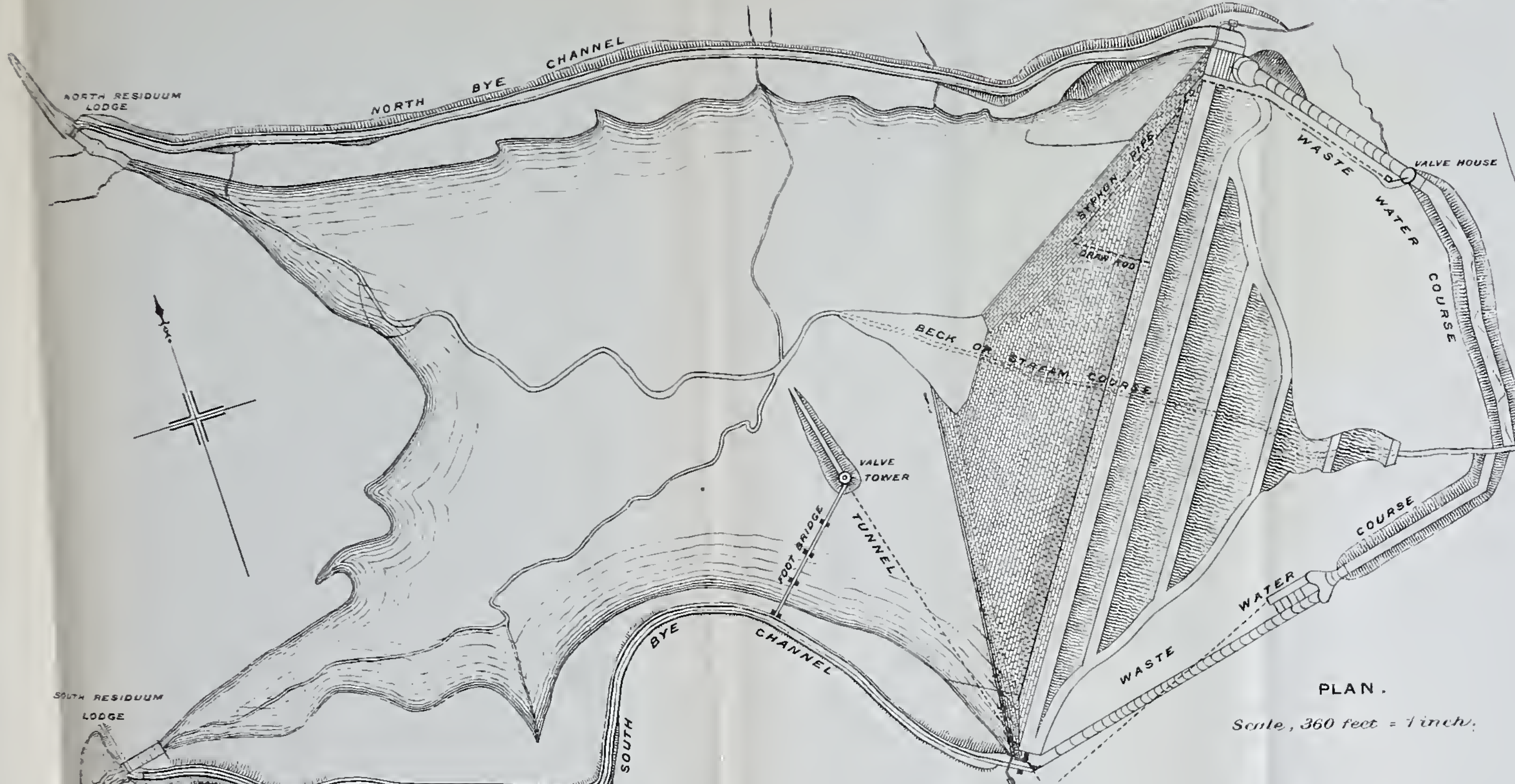


Some Engineers consider that this toe should be of hand packed rubble, and that the embankment bed should be cut in long indentations as shown in dotted lines.

PLATE XIV.

BRADFORD CORPORATION WATER WORKS.

UPPER BARDEN RESERVOIR.

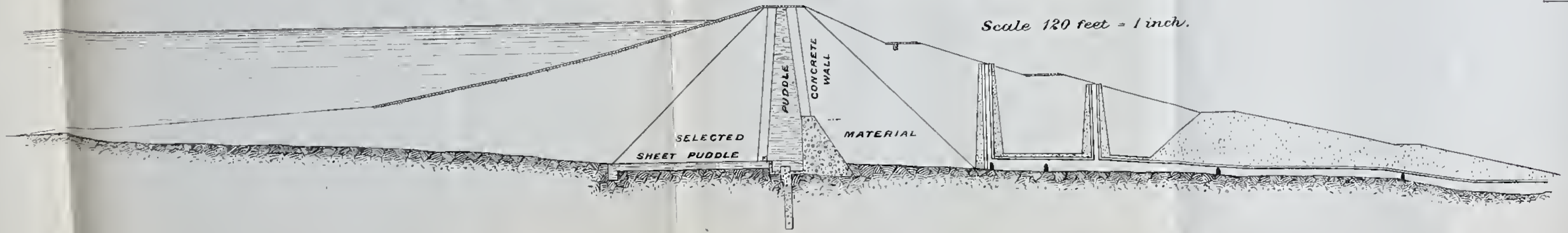


PLAN.

Scale, 360 feet = 1 inch.

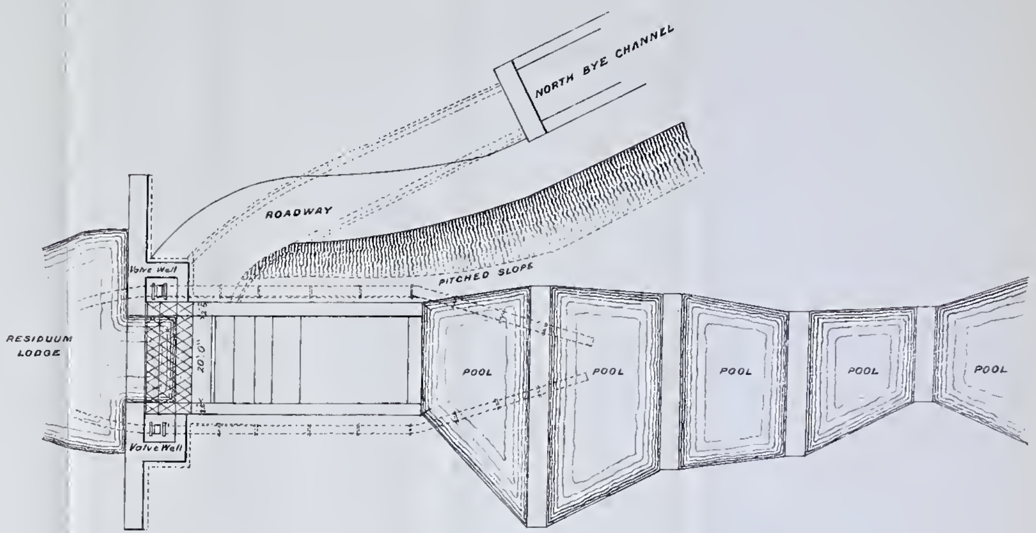
TRANSVERSE SECTION OF MAIN EMBANKMENT ON LINE OF BECK.

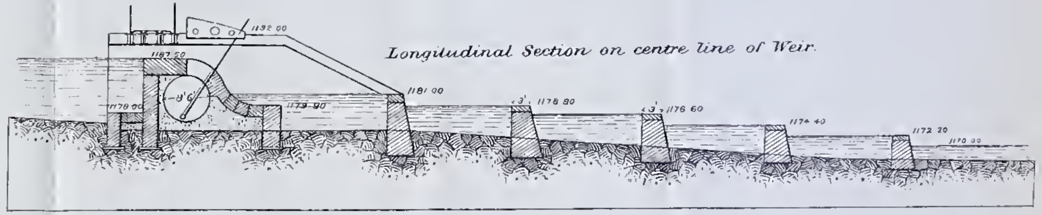
Scale 120 feet = 1 inch.



RESIDUUM LODGE ON YETHERSGILL.

Plan of Masonry Bye Channel and Pipes.





Longitudinal Section on centre line of Weir.

BRADFORD CORPORATION WATER WORKS.

PLATE XVI.

UPPER BARDEN RESERVOIR.

PLAN
SHEWING WASTE WEIR, BYE CHANNEL & GILL BECK FEEDER AT NORTH END OF EMBANKMENT.

Scale, 36 feet = 1 inch.

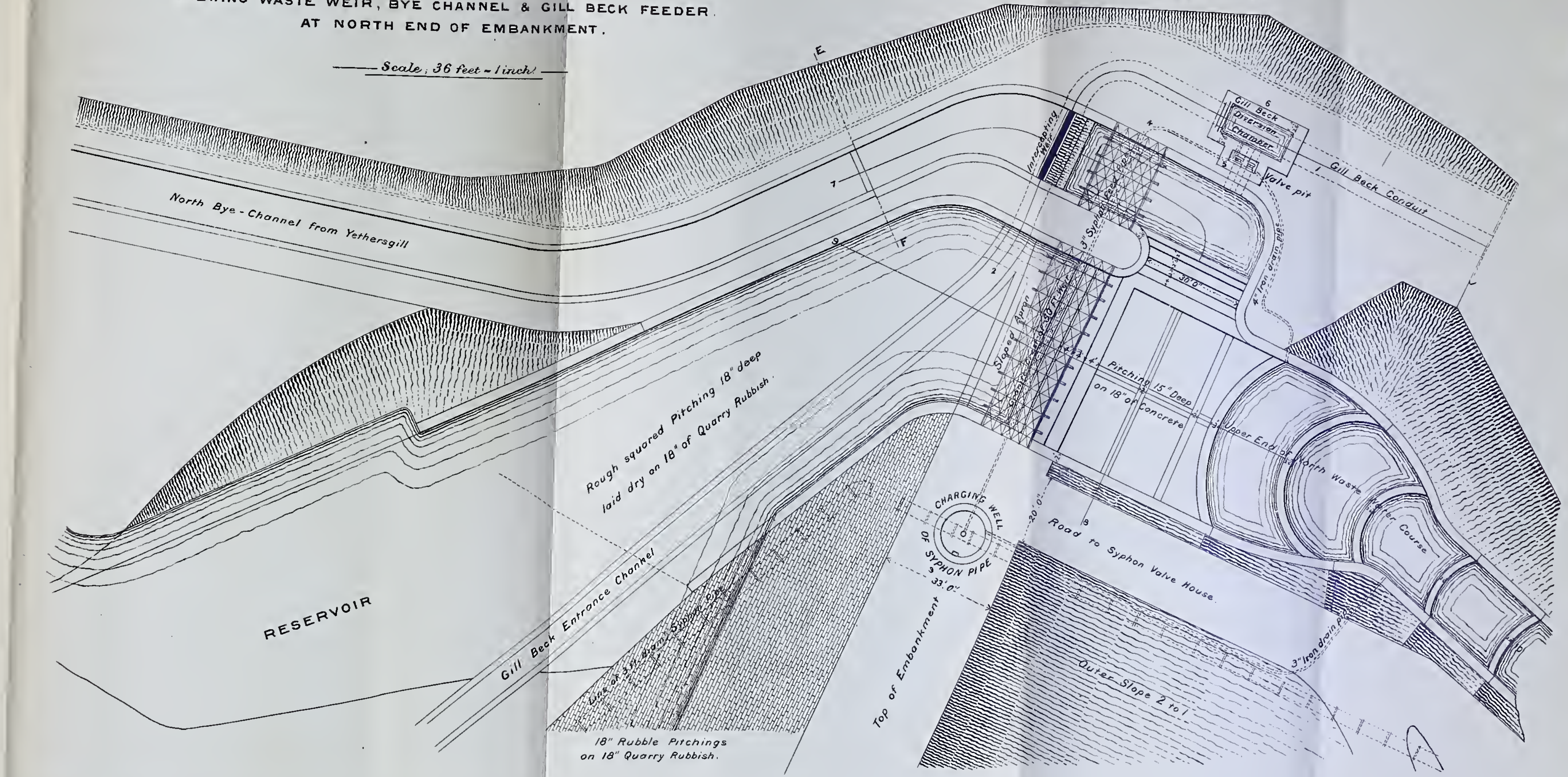

North Bye-Channel from Yethersgill
E
F
7
9
2
4
6
5
1
3
8
Intercepting Weir
Gill Beck Diversion Chamber
Valve pit
Gill Beck Conduit
3" Syphon feed pipe
4" Iron drain pipe
30'0"
Sloped Apron
Granite Crest of 30 Ft. Weir
4' Pitching 15" Deep on 18" of Concrete
Upper End of North Waste Water Course
Rough squared Pitching 18" deep laid dry on 18" of Quarry Rubbish.
CHARGING WELL of SYPHON PIPE
20'0"
33'0"
Road to Syphon Valve House.
Top of Embankment
Outer Slope 2 to 1
3" Iron drain pipe
Gill Beck Entrance Channel
Line of 3 ft. diam. Syphon Pipe
18" Rubble Pitchings on 18" Quarry Rubbish.
RESERVOIR

PLATE XVII.

SECTIONS OF WASTE WATERCOURSES.

Fig. 1.

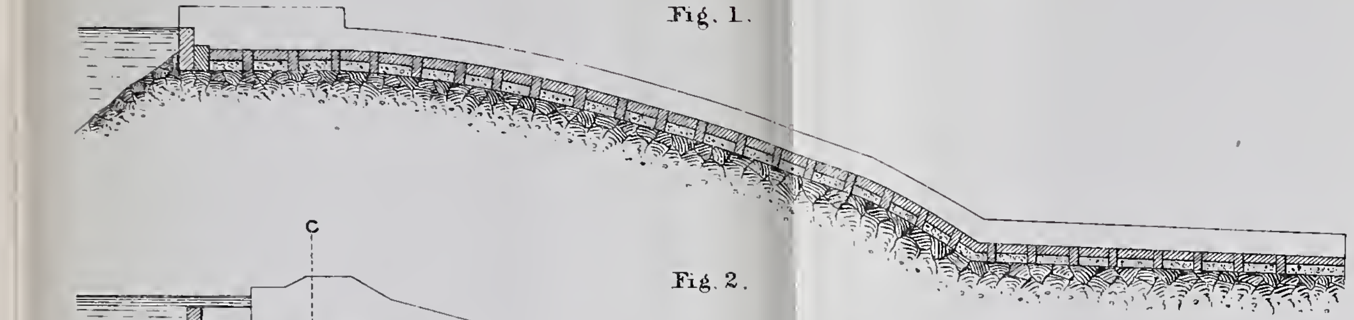


Fig. 2.

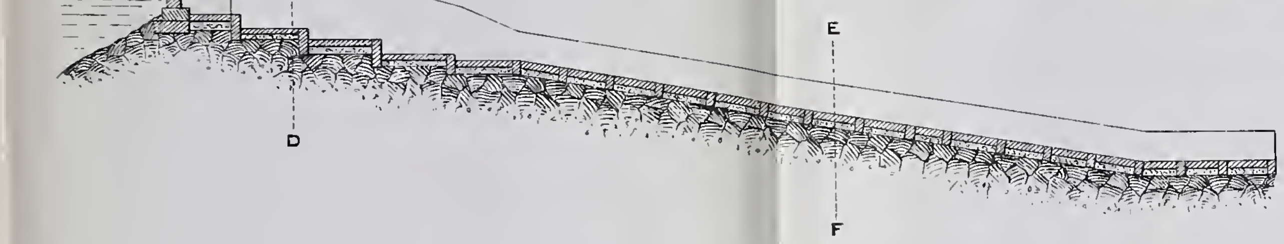


Fig. 3.
Section C-D.

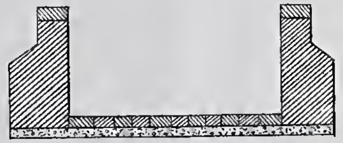
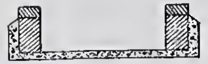


Fig. 4.
Section E-F.



WASTE WATERCOURSE WITH POOLS.

Fig. 5.
PLAN.
Scale, 16 feet to 1 Inch.

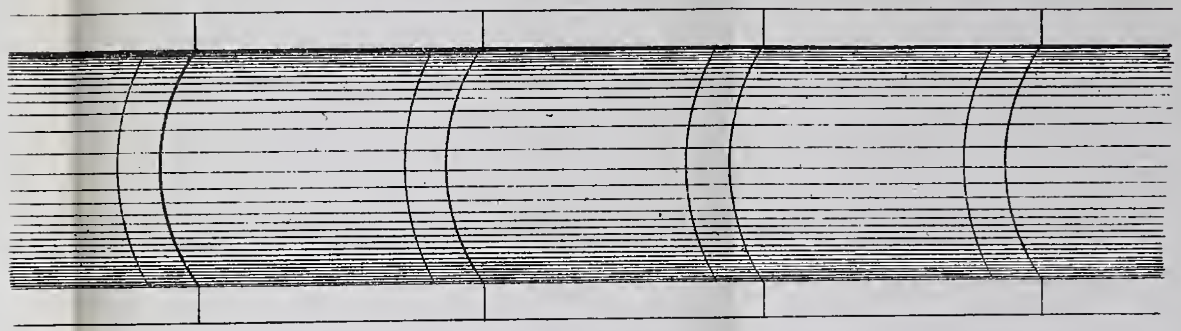
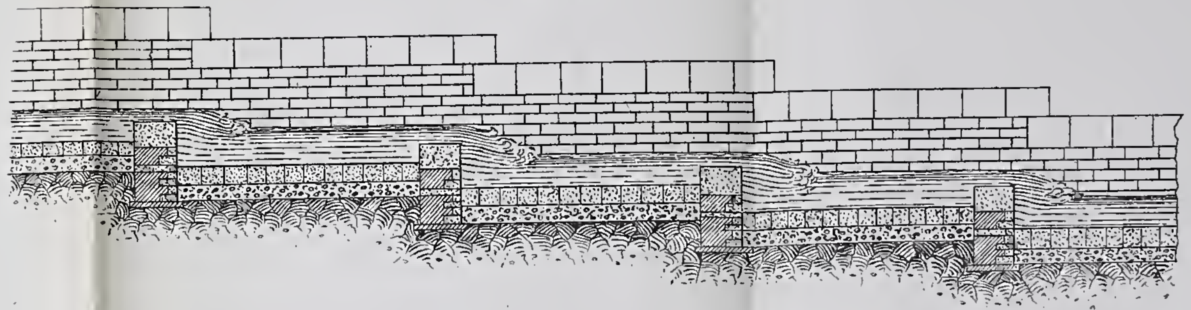


Fig. 6.
SECTION.



OVERFLOW ARRANGEMENTS IN A RESERVOIR.

PLATE XVIII.

Fig. 1.

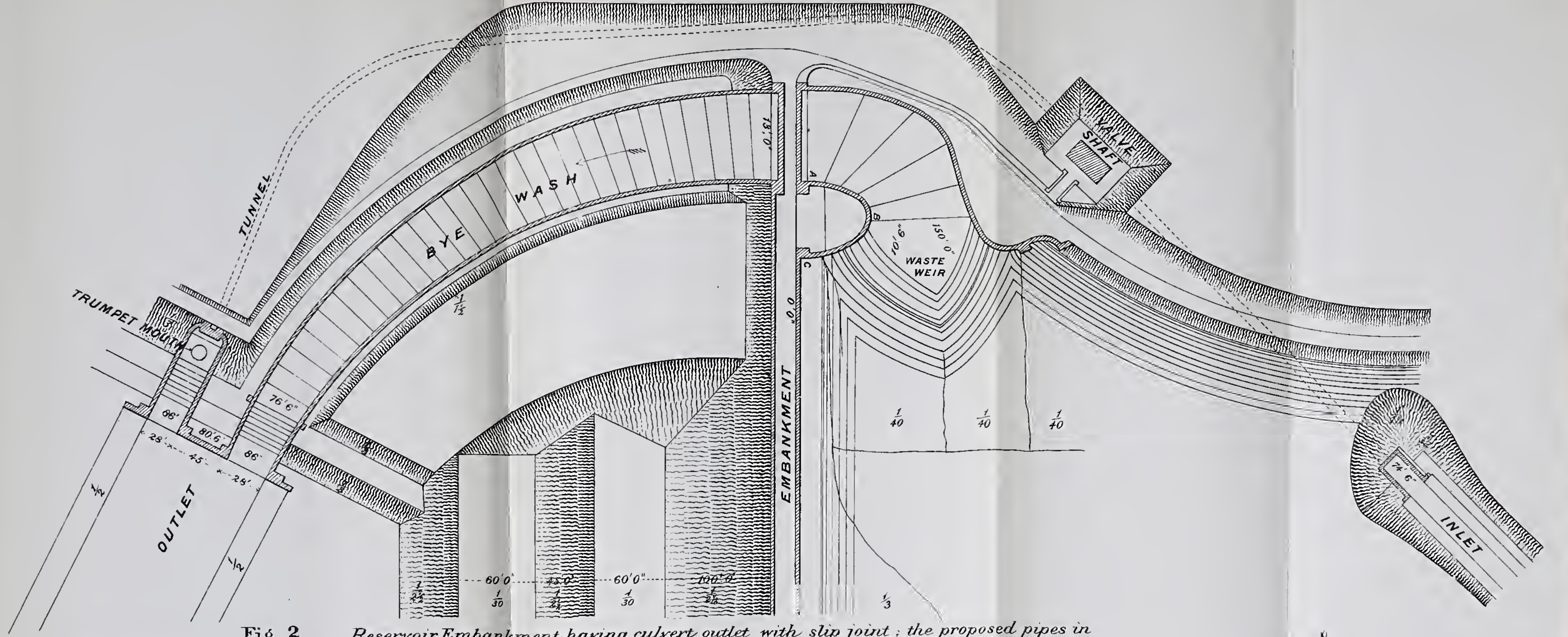


Fig. 2. *Reservoir Embankment having culvert outlet with slip joint; the proposed pipes in which commence at a wrought iron shield in slip joint with valve at outer end.*

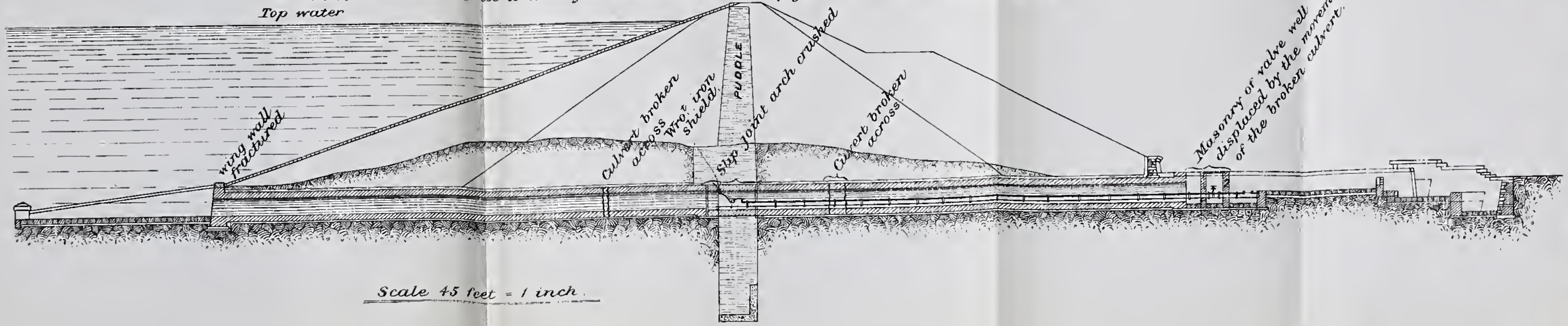
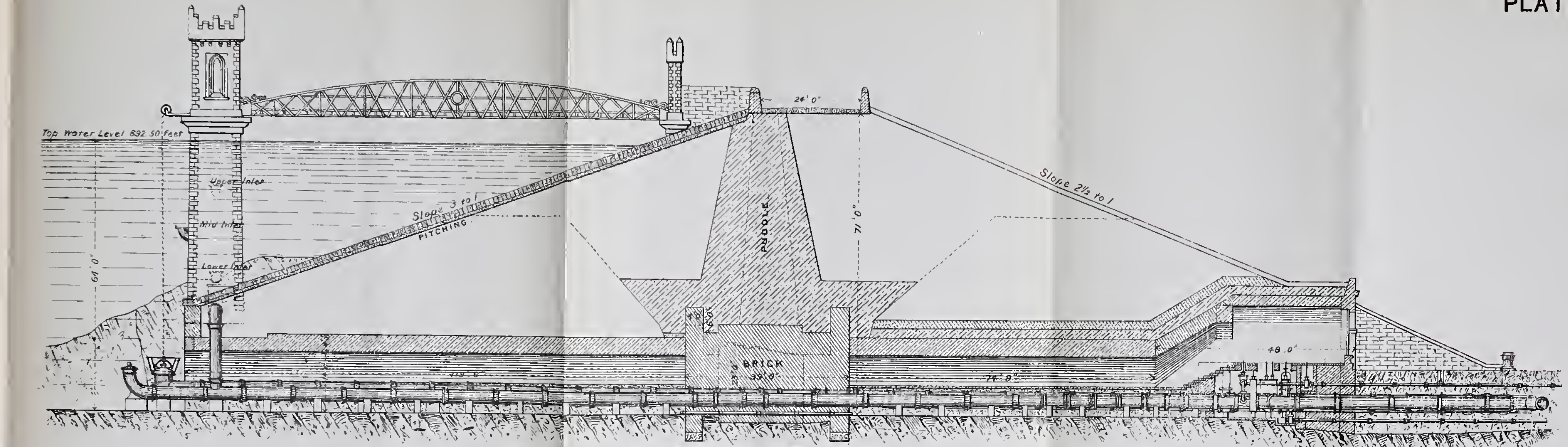
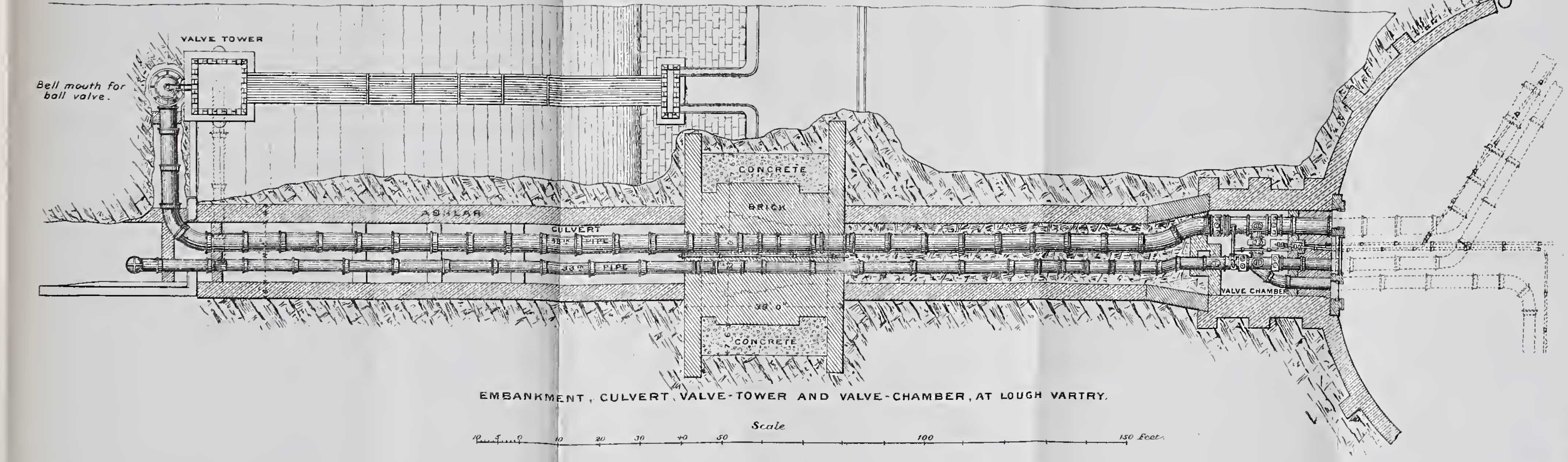


PLATE X



SECTION A TO B ON PLAN.



EMBANKMENT, CULVERT, VALVE-TOWER AND VALVE-CHAMBER, AT LOUGH VARTRY.

Scale

10 0 10 20 30 40 50 100 150 Feet.

PLATE XX.

TUNNEL OUTLET.

$\frac{1}{20}$ FULL SIZE

Fig. 1.

TRANSVERSE. SECTION.

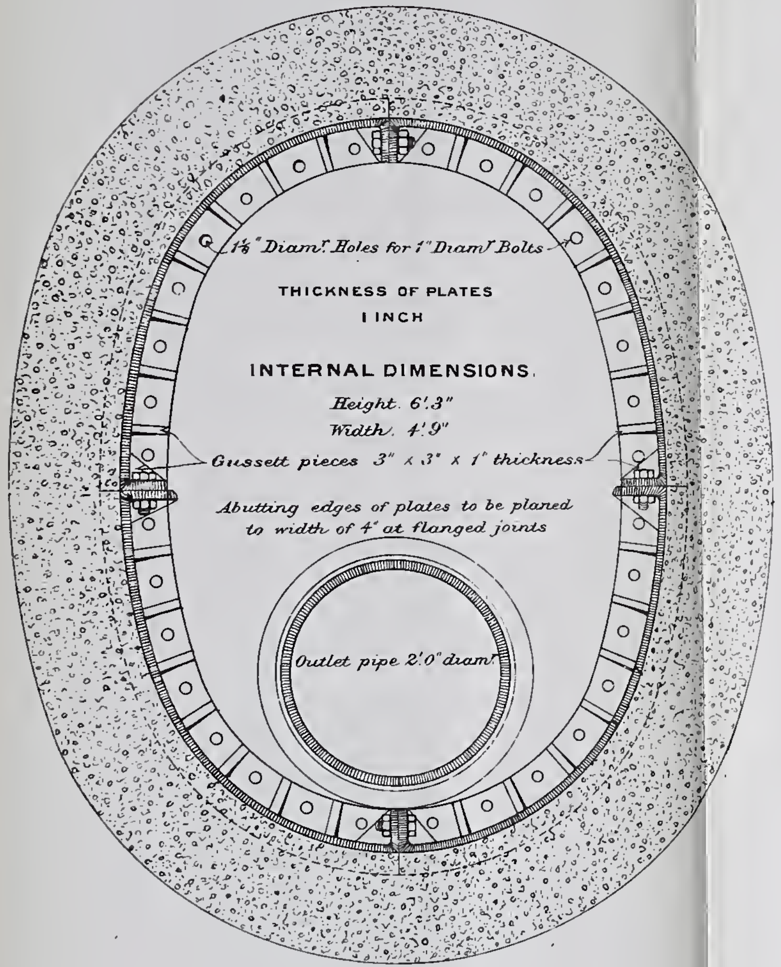
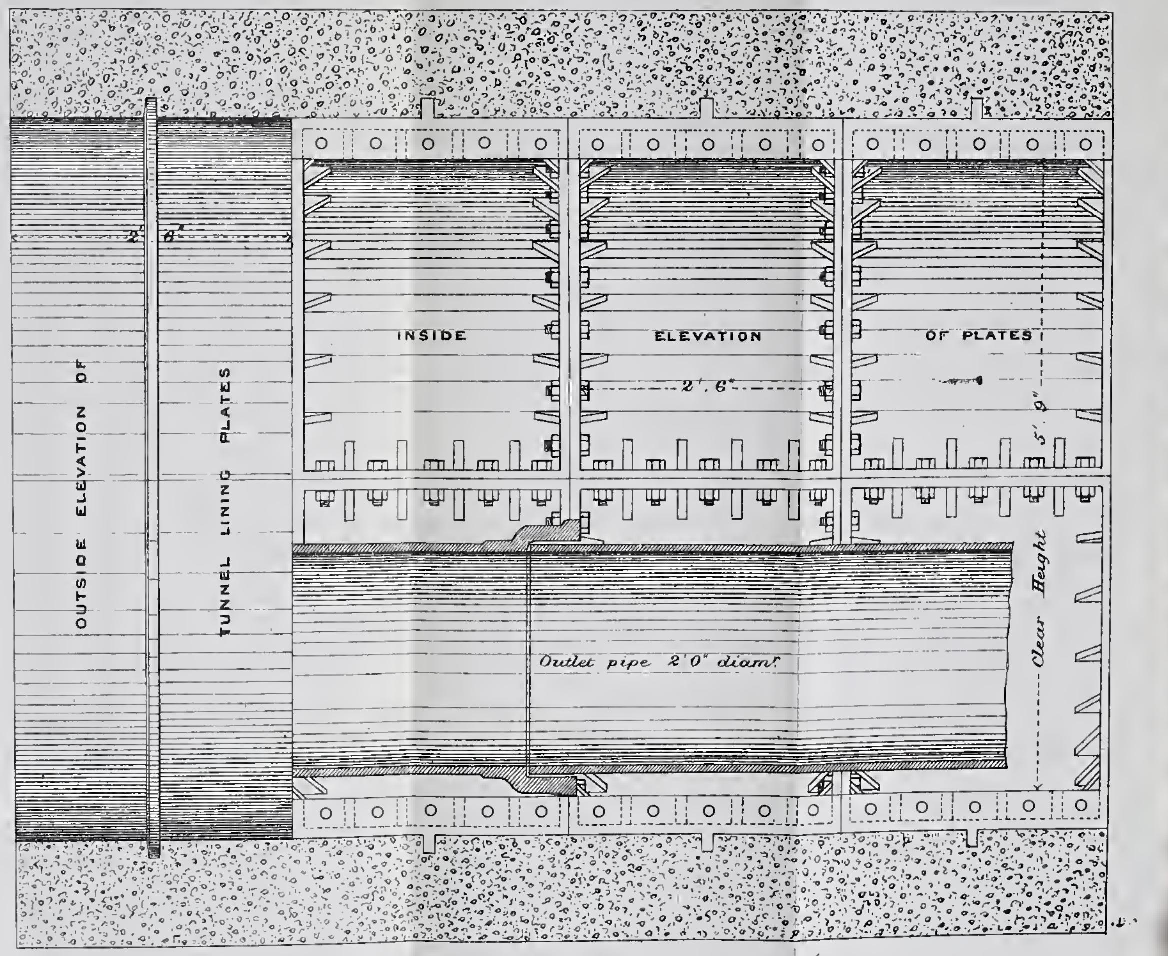

1⅛" Diamr. Holes for 1" Diamr. Bolts
THICKNESS OF PLATES
1 INCH
INTERNAL DIMENSIONS.
Height. 6'.3"
Width. 4'.9"
Gussett pieces 3" × 3" × 1" thickness
Abutting edges of plates to be planed to width of 4" at flanged joints
Outlet pipe 2'.0" diamr.

Fig. 2.

LONGITUDINAL SECTION.

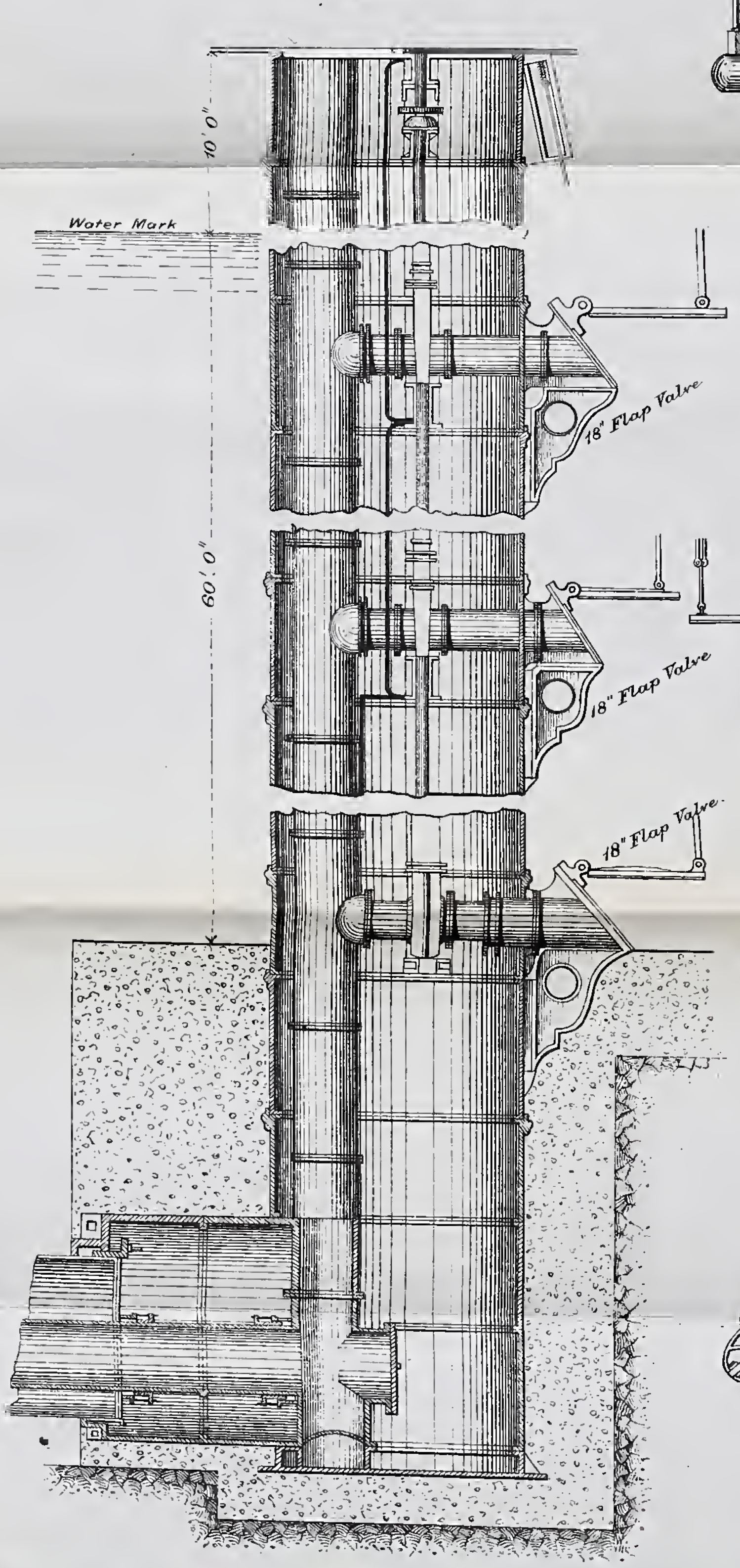
CAST IRON PLATES 2' 6" LONG 1 IN. METAL.



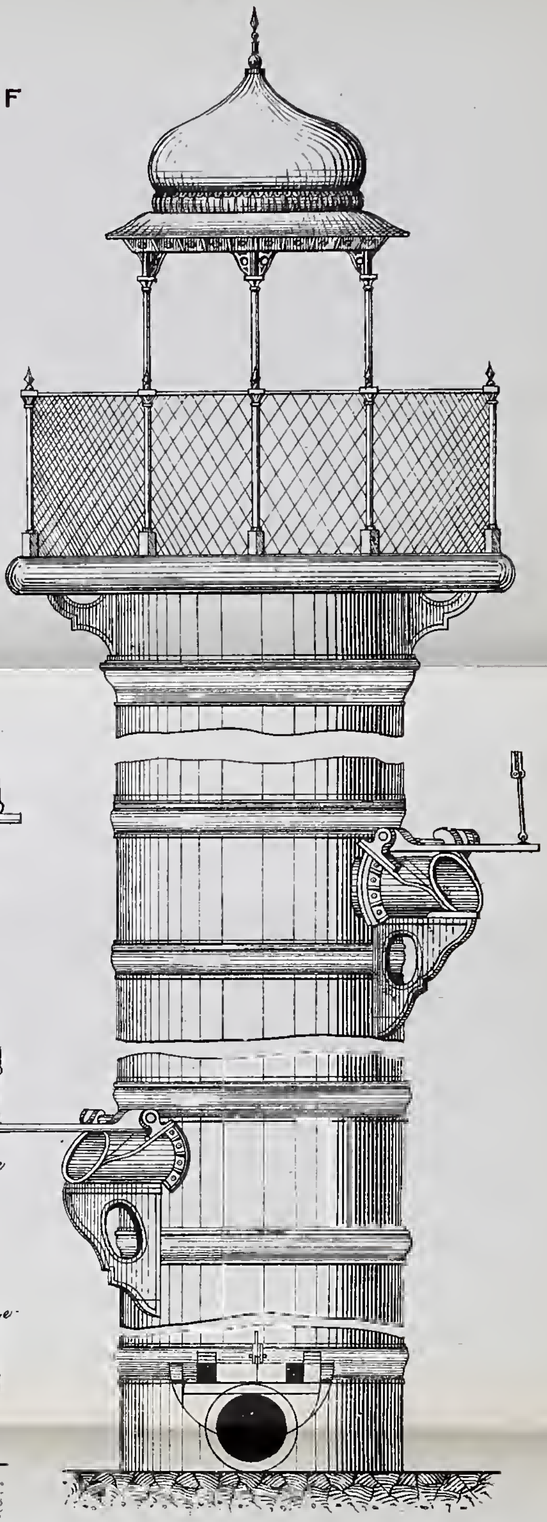
PLAN, ELEVATION AND SECTION OF CAST IRON VALVE TOWER.

Scale : 14 feet = 1 inch.

SECTION.



ELEVATION.



PLAN.

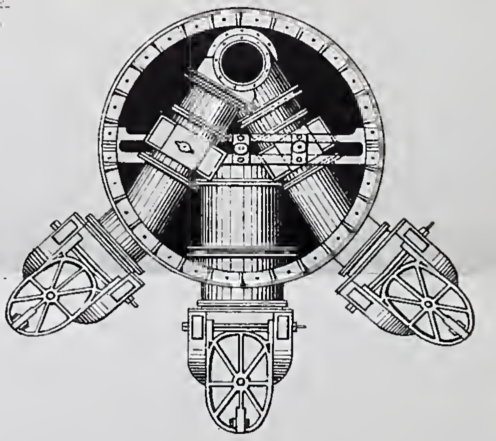


PLATE XXI.

VALVE TOWERS.

PLATE XXII.

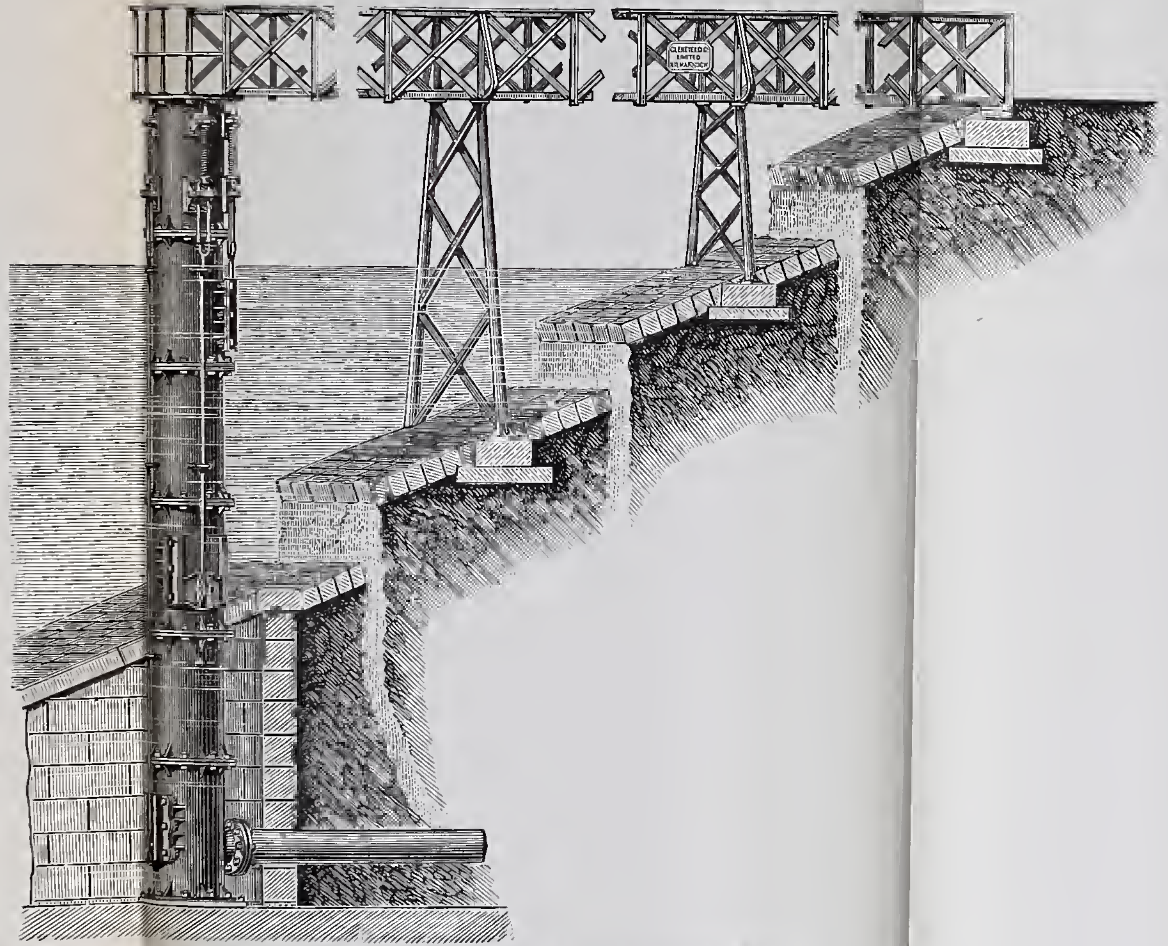


FIG. 1.—Cast-Iron Valve Tower with Approach Bridge.

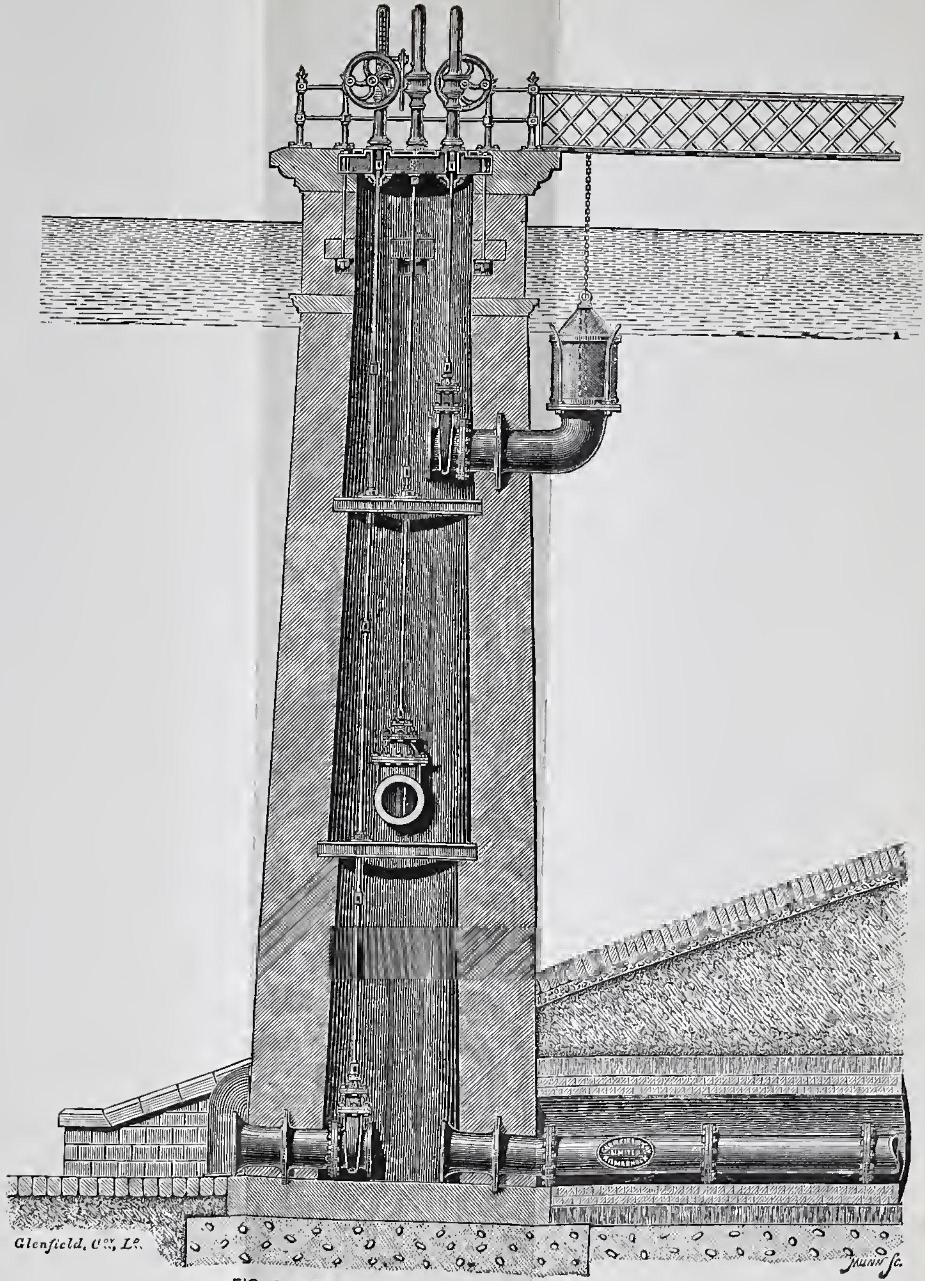


FIG. 2.—Masonry Valve Tower with Approach Bridge.

PLATE XXIII.

Fig. 1.

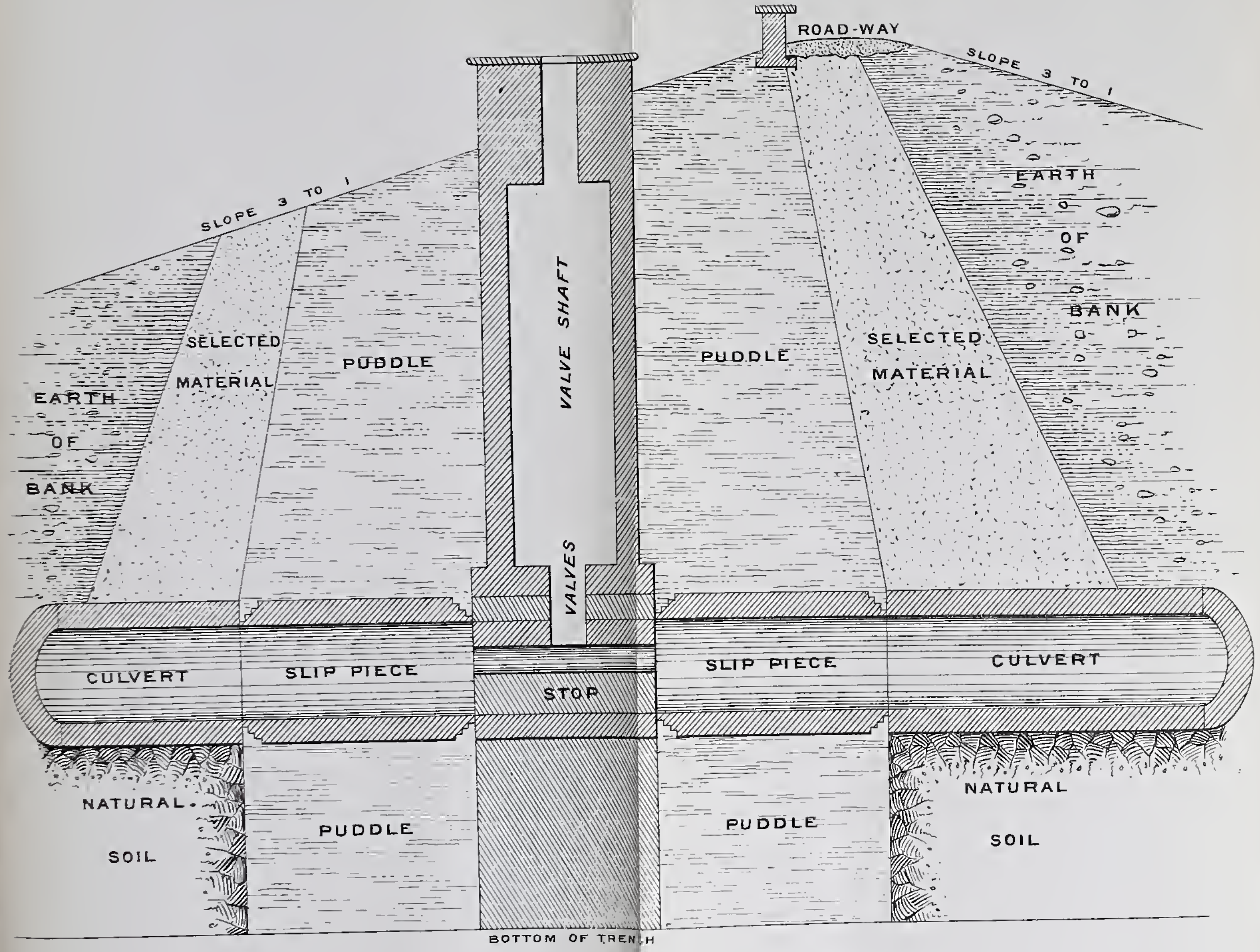
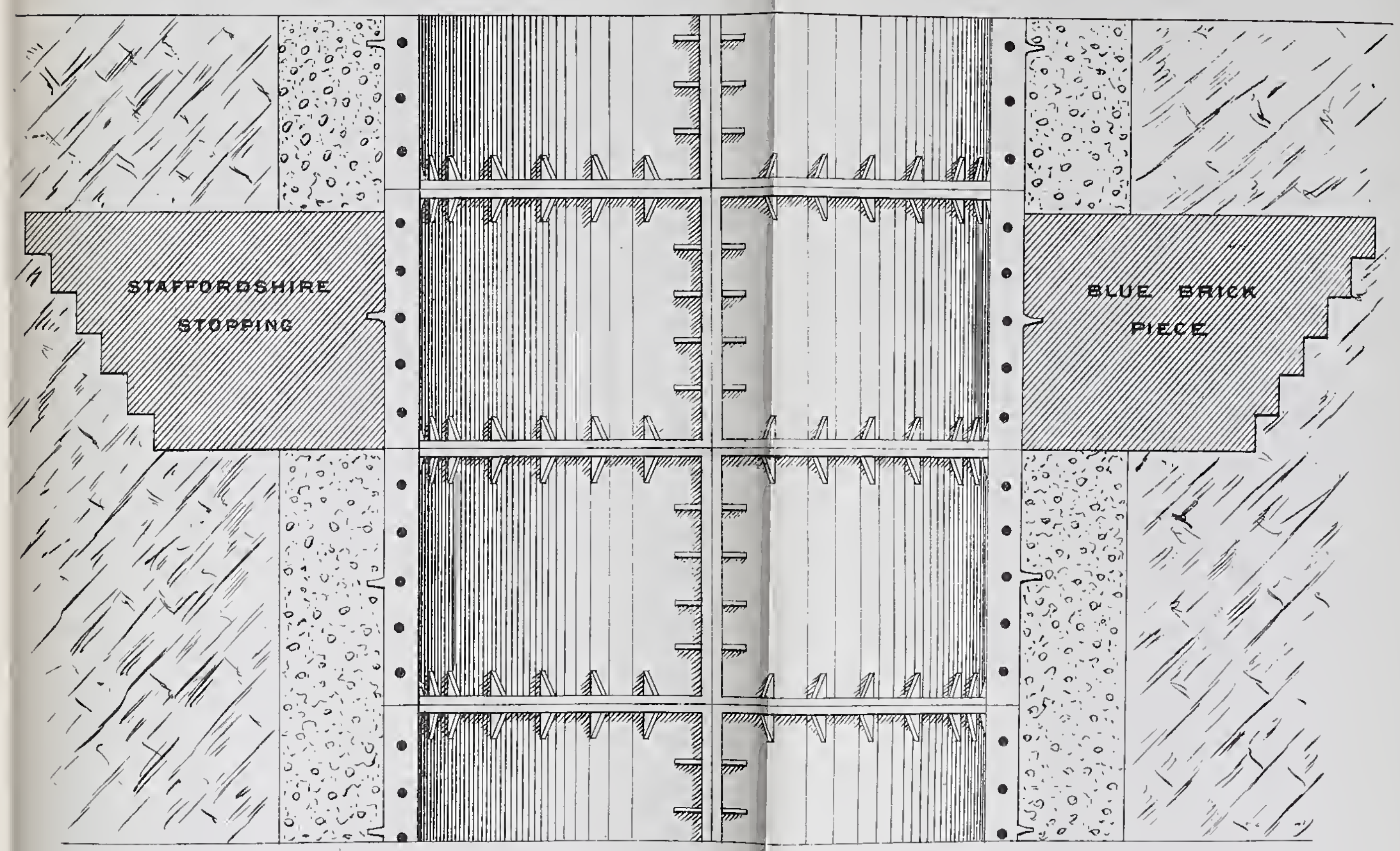


Fig. 2.

LONGITUDINAL SECTION OF TUNNEL OUTLET

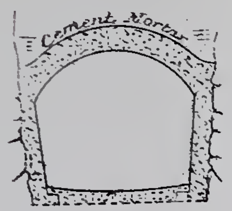
Shewing Stopping Piece.



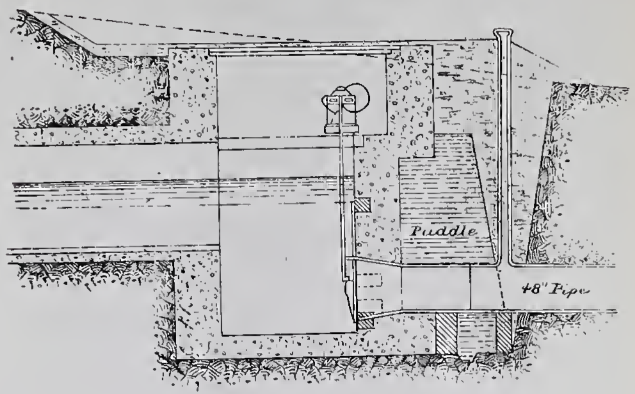
THE GLASGOW WATER WORKS.

Valve Chamber and Bridge on Loch Katrine Aqueduct.

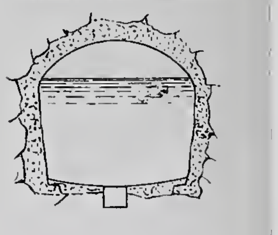
OPEN CUTTING IN ROCK



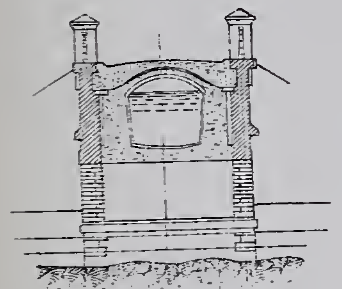
VALVE CHAMBER.

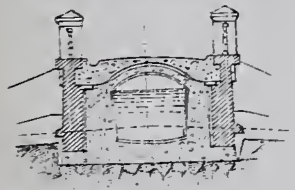


TUNNEL IN ROCK
LINED ALL ROUND.



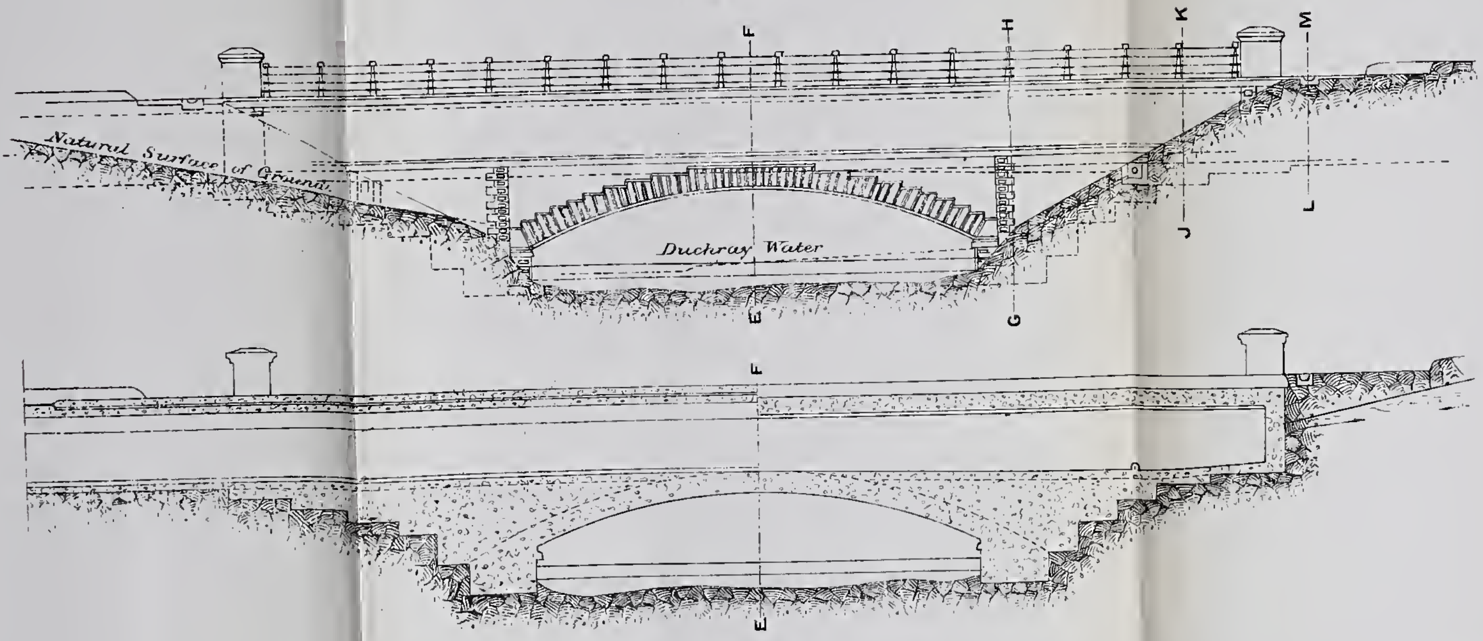
SECTION E-F



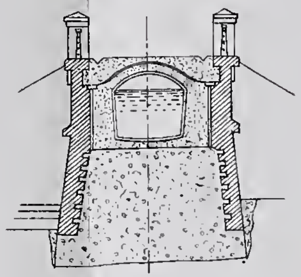


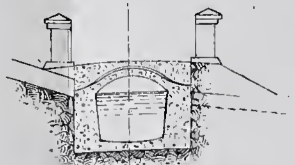
SECTION J-K

ELEVATION.



SECTION G-H.



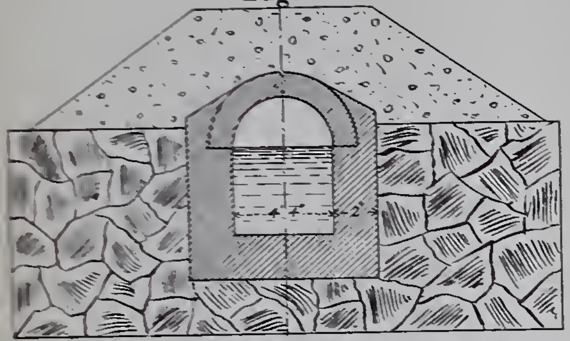


SECTION L-M.

SECTIONS OF CONDUITS IN VARIOUS WATER WORKS.

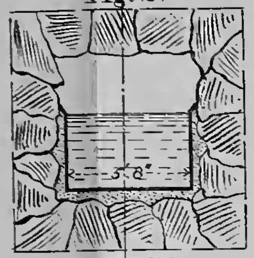
PLATE XXV.

Fig. 1.



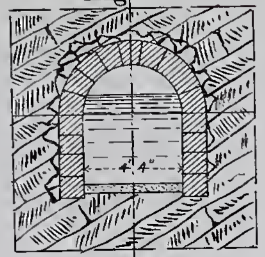
VIENNA.

Fig. 2.



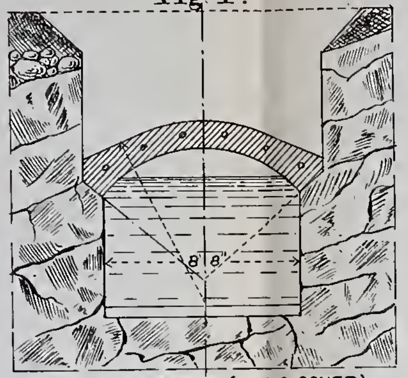
VIENNA.

Fig. 3.



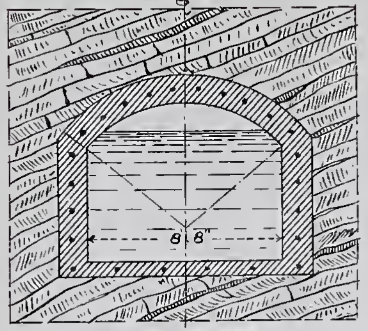
VIENNA.

Fig. 4.



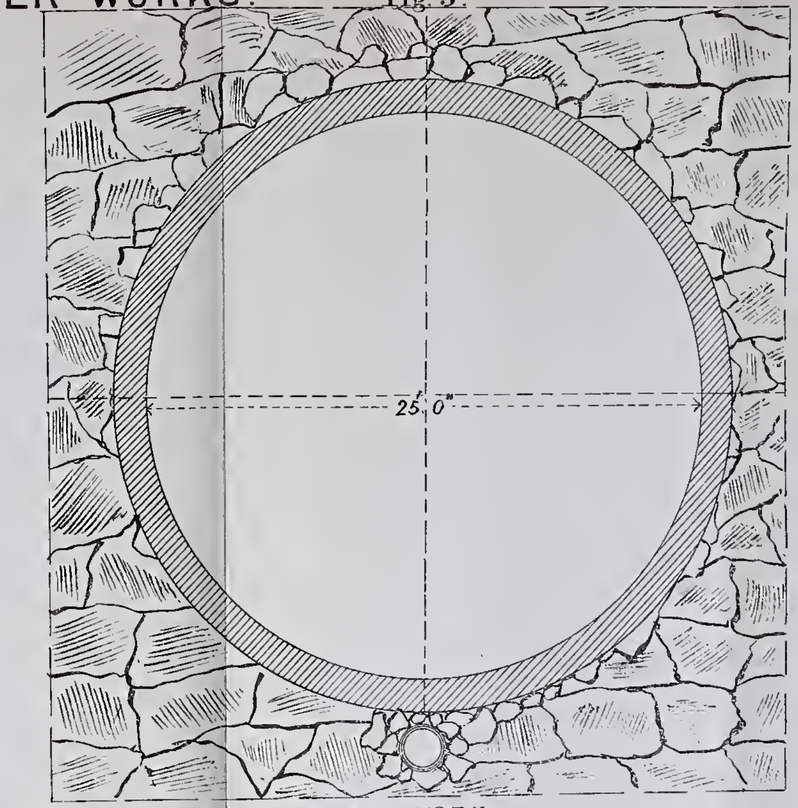
MANCHESTER (CUT & COVER)

Fig. 4.



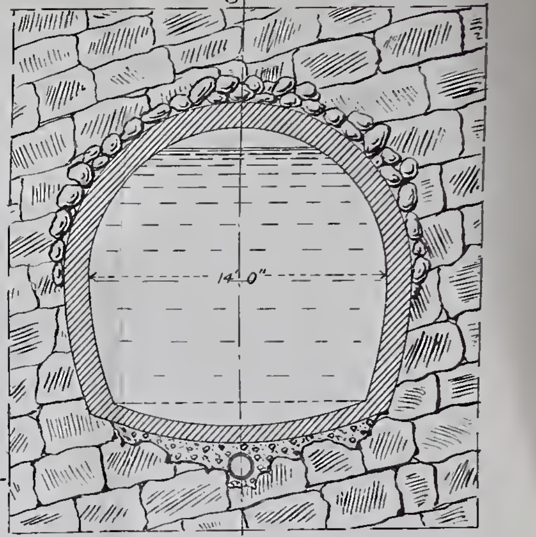
MANCHESTER.

Fig. 5.



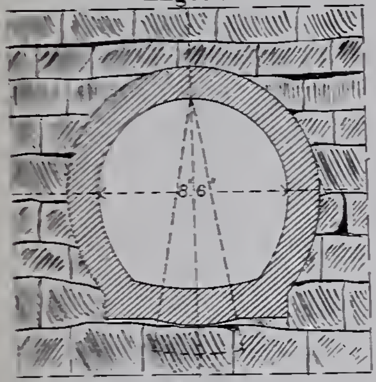
NEW YORK.

Fig. 6.



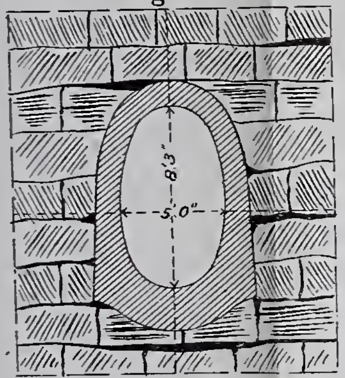
NEW YORK.

Fig. 7.



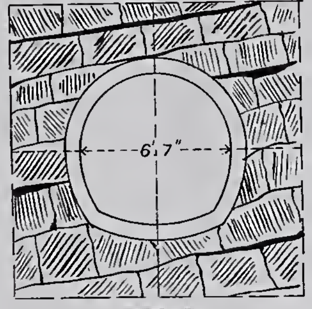
GLASGOW.

Fig. 8.



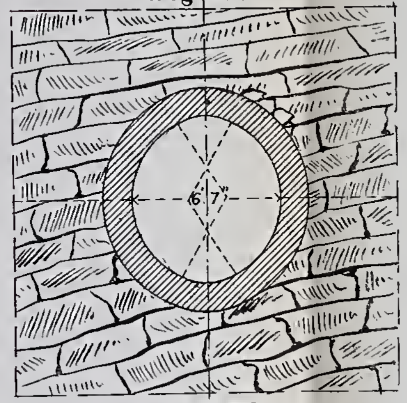
LILLE.

Fig. 9.



PARIS.

Fig. 10.



NAPLES.

Fig. 11.

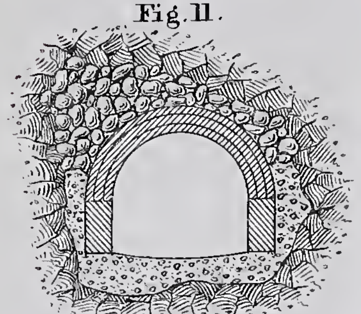


Fig. 12.

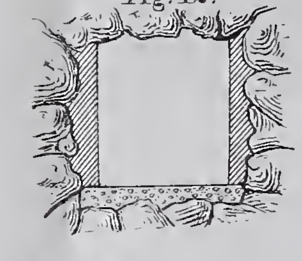


Fig. 13.

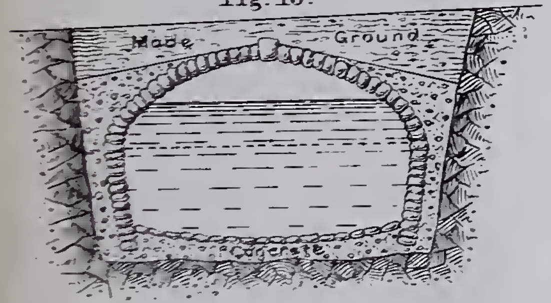


Fig. 14.

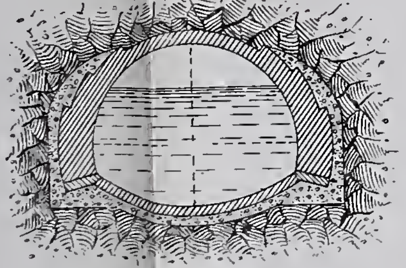


Fig. 15.

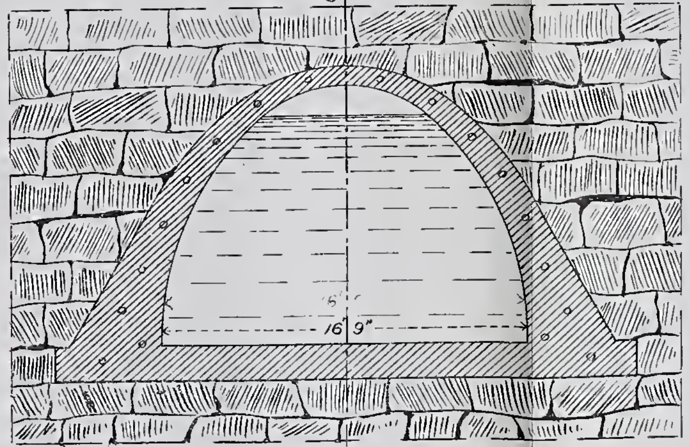
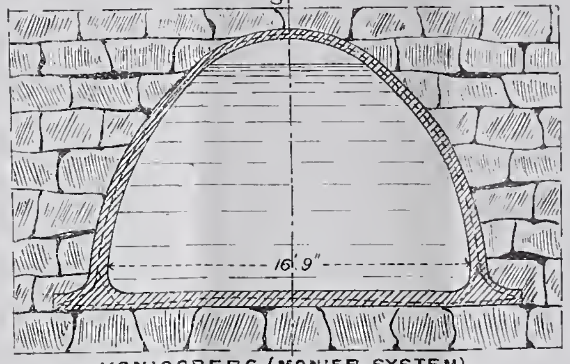


Fig. 16.



KONIGSBERG (MONIER SYSTEM)

Fig. 17.

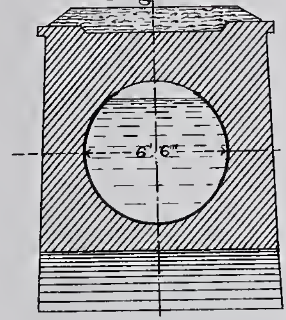
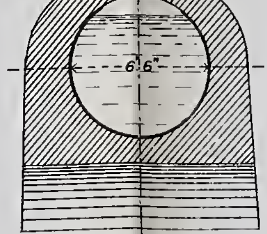


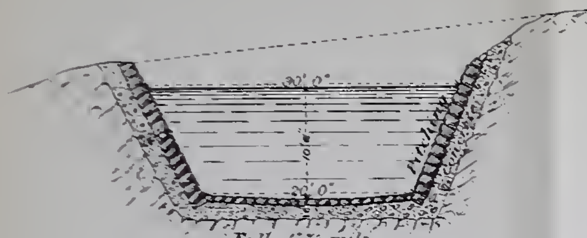
Fig. 18.



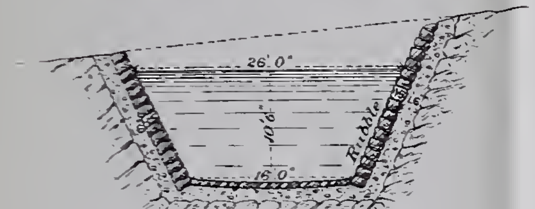
SECTIONS SHEWING THE MODES OF CONSTRUCTION PROPOSED FOR MAIN AQUEDUCTS IN THE ROYAL COMMN. FOR WATER SUPPLY 1869.

PLATE XXVI.

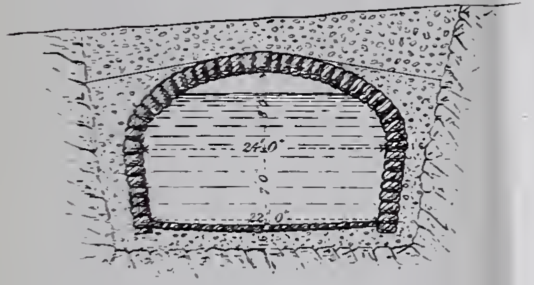
IN ROCK



Fall, 4" ℘ mile.
Velocity, 109 ft ℘ minute.
Discharge, 28·340 c.f ℘ minute.

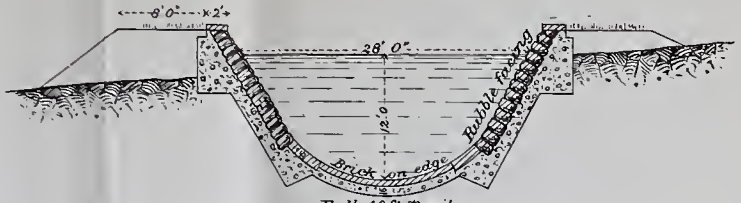


Fall, 6" ℘ mile.
Velocity, 128 ft. ℘ minute.
Discharge, 27·702 c.f ℘ minute.

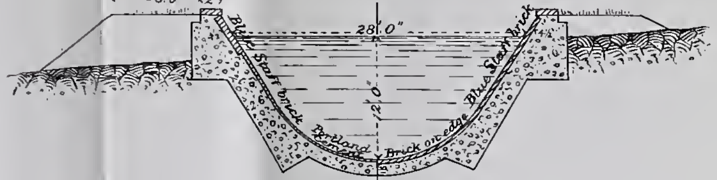


Fall, 4" ℘ mile.
Velocity, 106 ft. ℘ minute.
Discharge, 28·514 c.f ℘ minute.

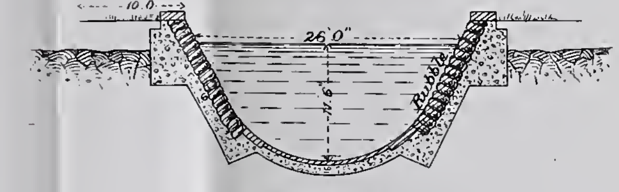
IN ORDINARY DISTRICTS.



Fall, 40 ft. ℘ mile.
Velocity, 119 ft. ℘ minute.
Discharge, 28·760 c.f. ℘ minute.

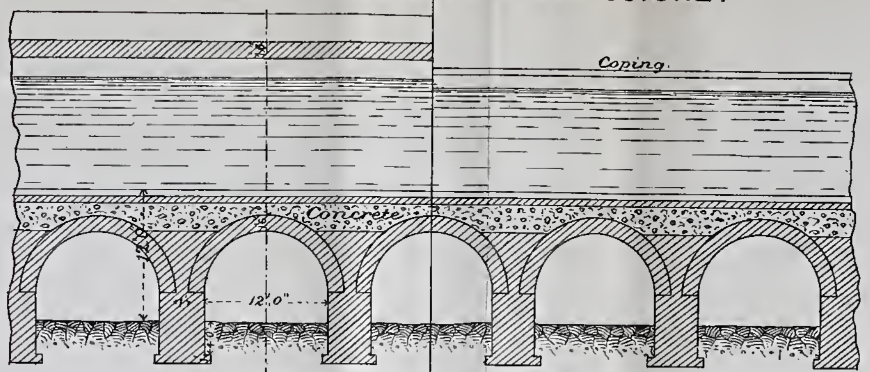


Full, 40 ft ℘ mile.
Velocity, 119 ft. ℘ minute.
Discharge, 28·760 c.f. ℘ minute.



Fall, 6" ℘ mile.
Velocity, 131 ft. ℘ minute.
Discharge, 28·361 c.f. ℘ minute.

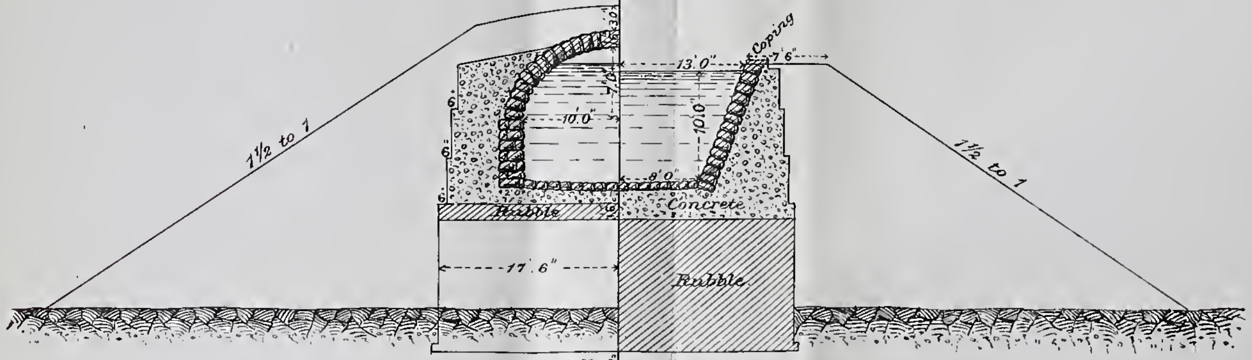
AQUEDUCT CARRIED ON SUBSTRUCTURE.



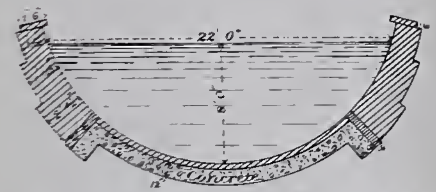
LONGITUDINAL SECTIONS.

TRANSVERSE SECTIONS.

Closed Open.



Fall 6" ℘ mile.
Velocity 128' 70 ℘ minute.
Discharge 27·750 c.f. ℘ minute.



Area 127 sq ft. – Wetted sides 29·2 feet – Fall 6" ℘ mile.

$\frac{127}{29.2} = 4.35$ H.M.D. $\sqrt{4.35 \times 1} = 2.08 \times \frac{10}{11}^{ths} = 1.9$ ft mean velocity.

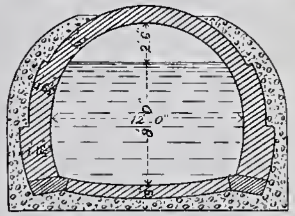
Area 127 × 1·9 = 241·3 c.f. per sec^d × 540 000 = 130,302,000 Gallons per day.

ESTIMATE PER LINEAL YARD.

Brickwork	4 cy	@	20/-	£4. 0. 0
Ashlar Coping &c.	12 cf	"	2/-	1. 4. 0
Concrete	2¼ cy	"	10/-	1. 2. 6
Excavation &c.	30 cy	"	2/-	3. 0. 0
				9. 6. 6
Sundries				0. 13. 6
				£10. 0. 0

BRANCH AQUEDUCT FROM SEVERN DISTRICT TO MARTEN MERE.

Covered Watercourse or Tunnel – average section.



Area 87·93 sq. ft. Wetted sides 26·5 feet – Fall 12" ℘ mile

$\frac{87.93}{26.5} = 3.31$ H.M.D. $\sqrt{3.31 \times 2} = 2.57 \times \frac{10}{11}^{ths} = 2.33$ ft mean velocity.

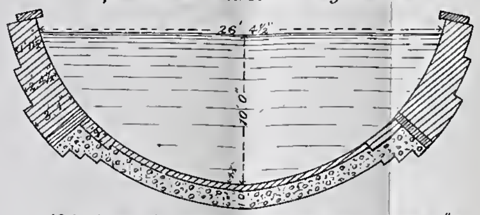
87·93 × 2·33 = 204·88 c.f per sec^d × 540,000 = 110,635,200 Gals. per day.

ESTIMATE PER LINEAL YARD.

Brickwork	5½ cy	@	20/-	£5 10. 0
Ashlar	13¼ cf	"	2/-	1. 6 6
Concrete	3¾ cy	"	10/-	1 17 6
Excavation &c.	36 cy	"	2/-	3 12 0
				12. 6. 0
Sundries				0. 14. 0
				£13 0 0

METROPOLIS WATER SUPPLY.
MAIN AQUEDUCT FROM MARTEN MERE TO SERVICE RESERVOIRS NEAR EDGEWARE.

Open Watercourse – average section.



Area 193·4 sq. ft. – Wetted sides 35 feet – Fall 6" ℘ mile.

$\frac{193.4}{35} = \sqrt{5.526 \text{ H.M.D.} \times 1} = 2.357 \times \frac{10}{11}^{ths} = 2.143$ ft mean velocity.

193·4 × 2·143 = 414·5 c.f. per sec^d × 540,000 = 224,000,000 Gals per day.

ESTIMATE PER LINEAL YARD.

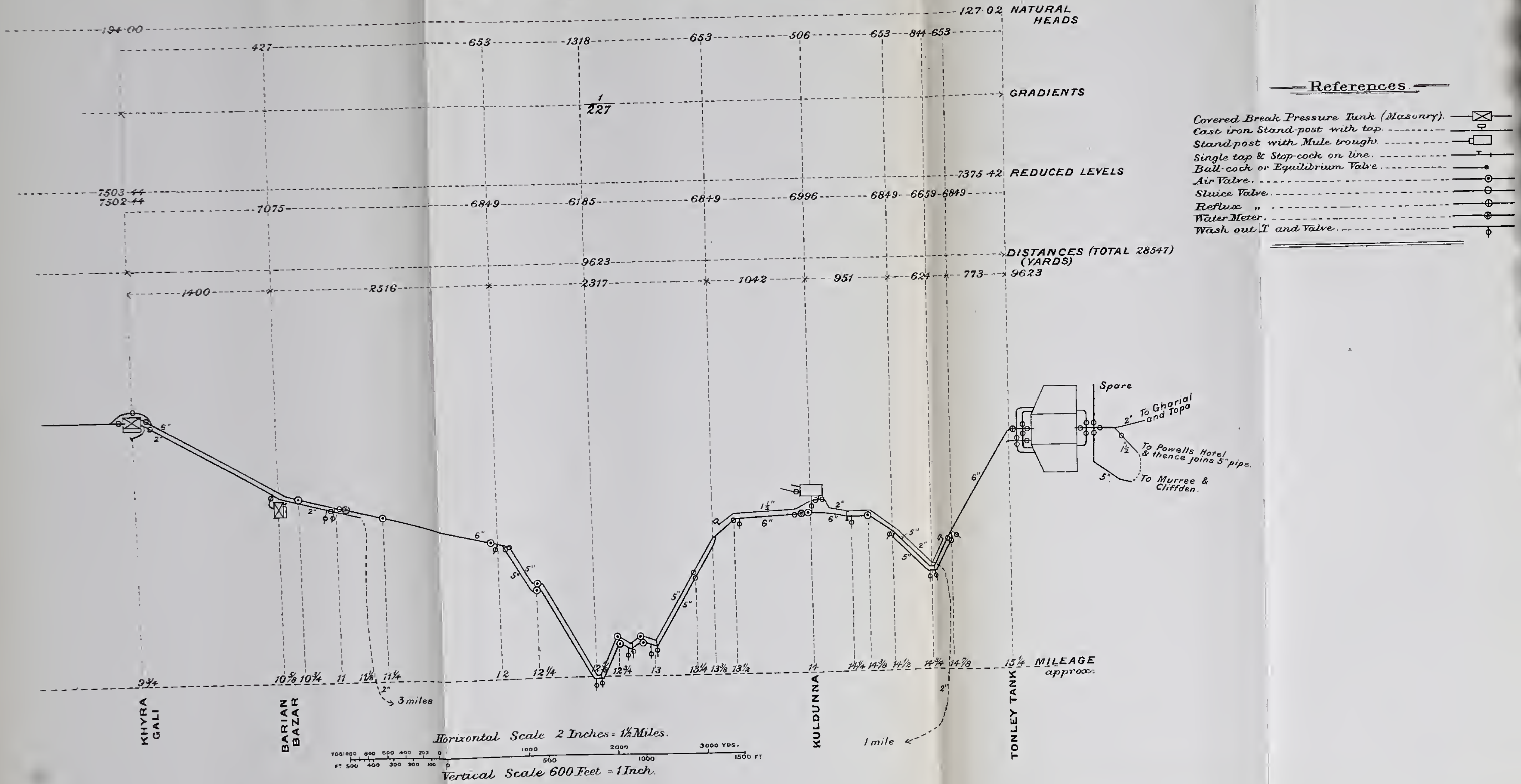
Brickwork	5¼ cy	@	20/-	£5. 5. 0
Concrete	4 cy	"	10/-	2. 0. 0
Ashlar skewbacks	14¼ c.f.	"	2/-	1. 8. 6
Excavation	35 c.y.	"	2/-	3. 10. 0
				12. 3. 6
Sundries				0. 6. 6
				£12. 10. 0

PLATE XXVII.

MURREE WATER SUPPLY.

PORTION OF CHART OF

SUPPLY MAIN FROM KHYRA GALI TO TONLEY RESERVOIR.



MURREE WATER SUPPLY.

INDEX PLAN OF COMPOUND SYPHON OF 6" AND 5" PIPES.

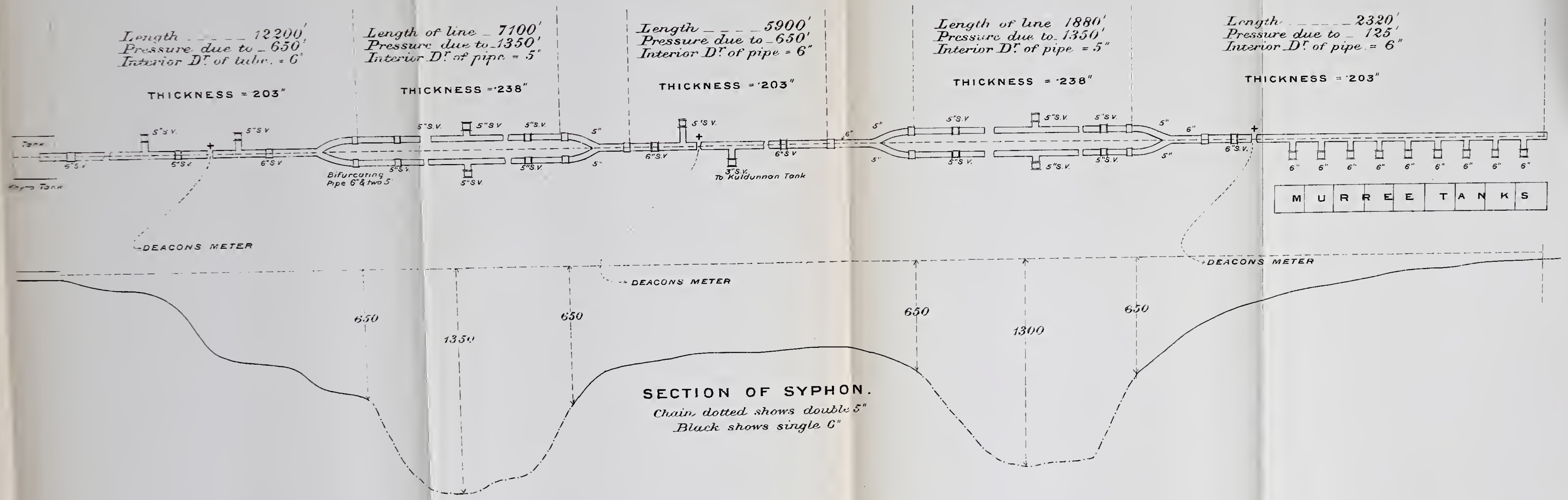
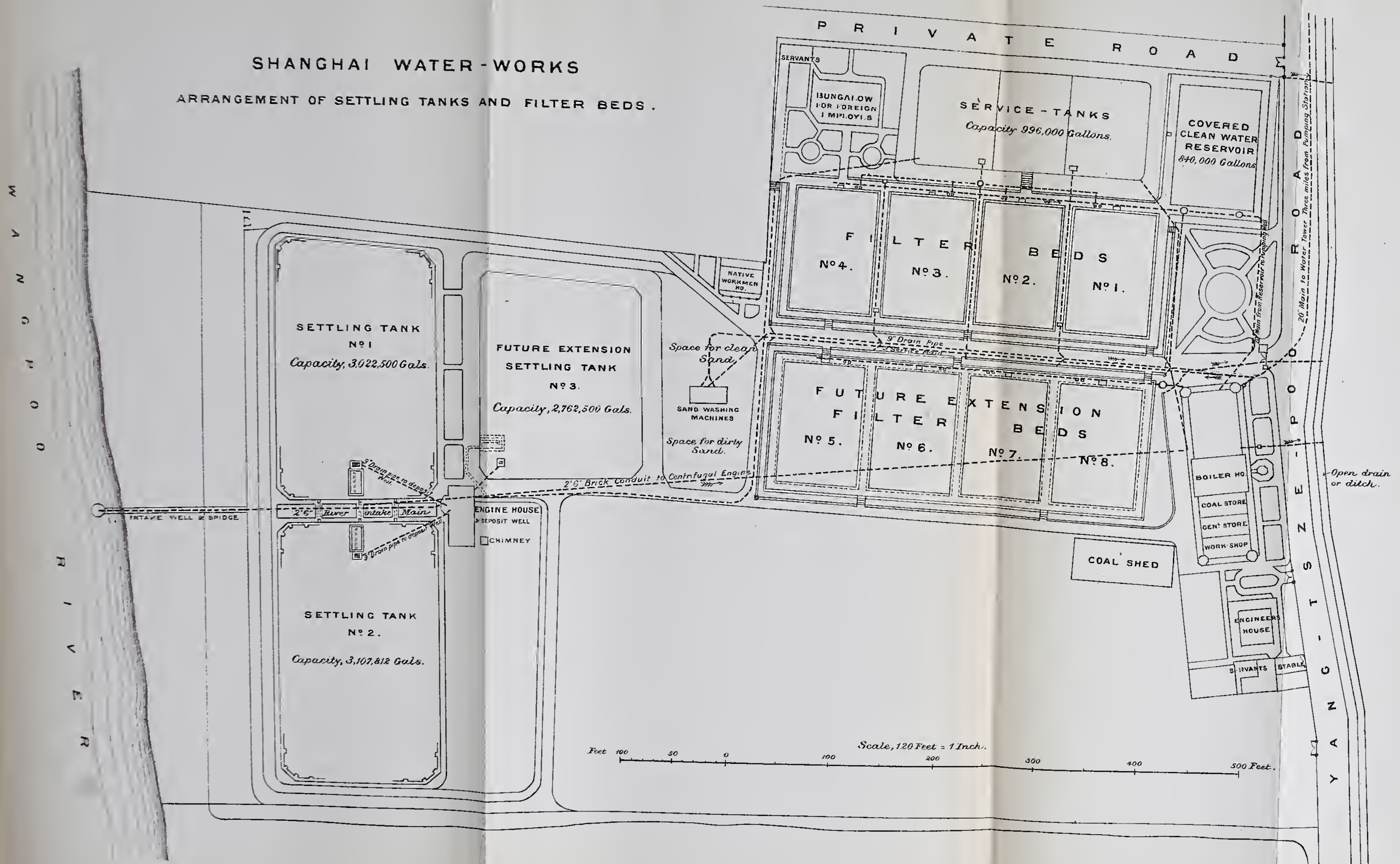


PLATE XXIX.

SHANGHAI WATER-WORKS

ARRANGEMENT OF SETTLING TANKS AND FILTER BEDS.



TRUSSED PIPE

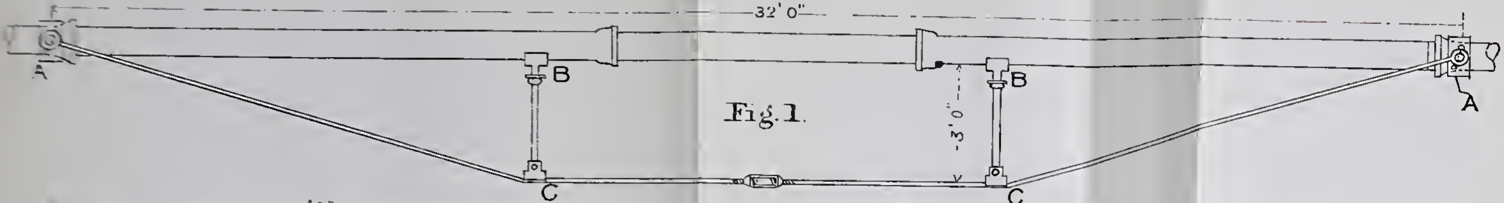


Fig. 1.

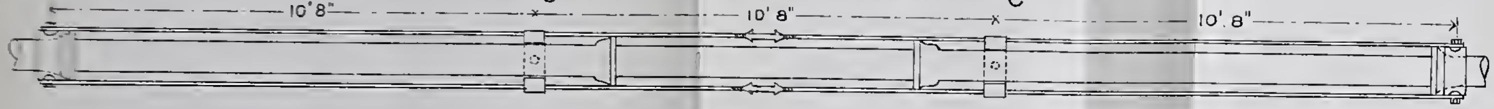


Fig. 2.

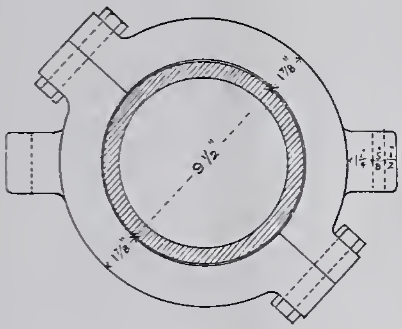


Fig. 4.

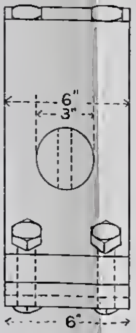


Fig. 3.

Detail of casting at A.

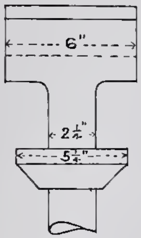
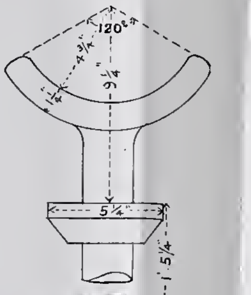


Fig. 6.

Detail at B.



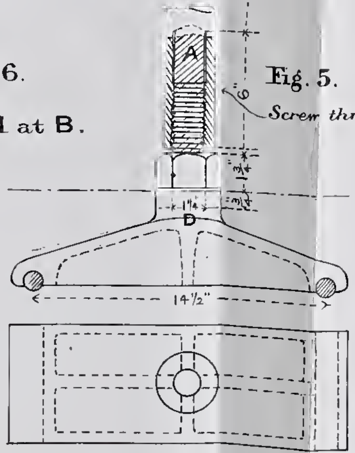


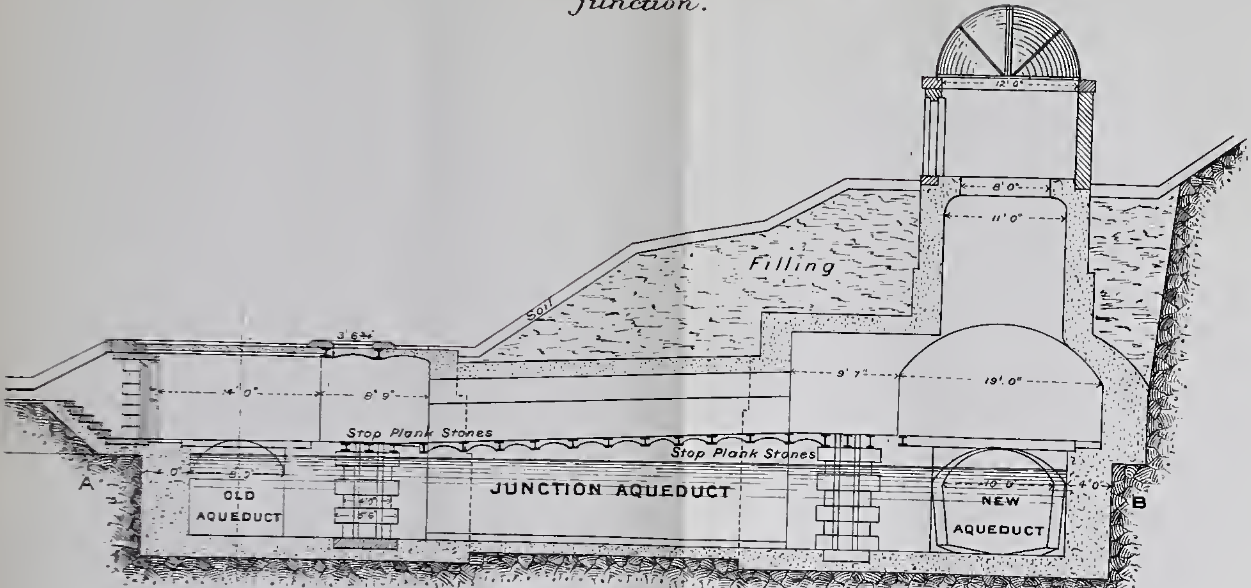
Fig. 5.

Detail at C.

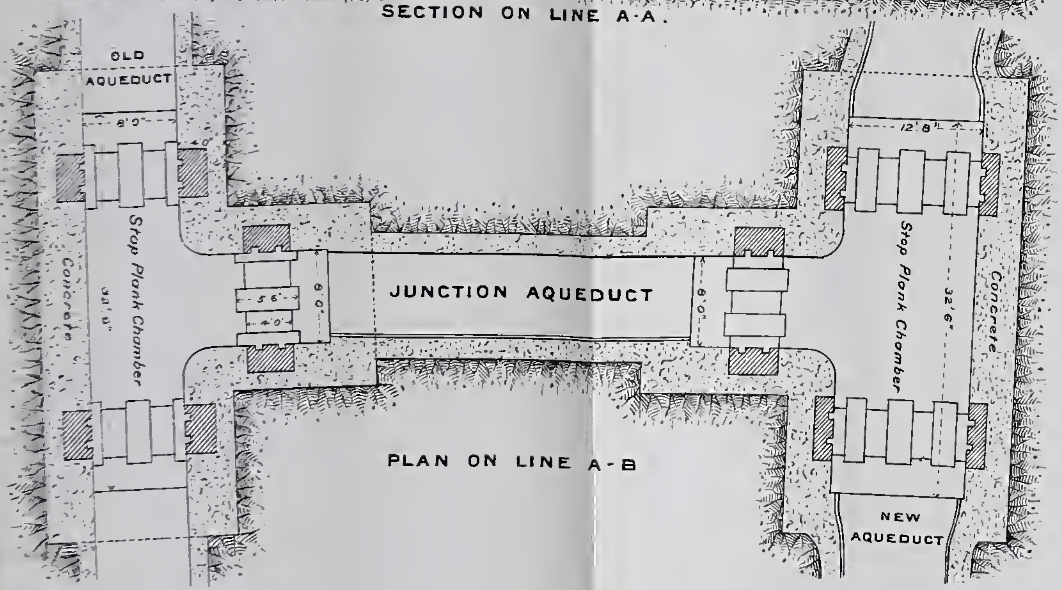
LOCH KATRINE AQUEDUCT.

PLATE XXXI.

Plan of Stop plank chambers & junction.



SECTION ON LINE A·A.



PLAN ON LINE A-B

SPECIAL BENDS AND OTHER CASTINGS USUALLY KEPT IN STOCK.

PLATE XXXII.

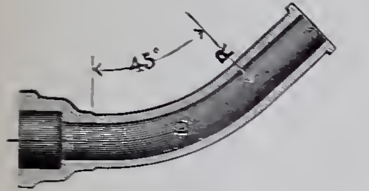


FIG. 1.

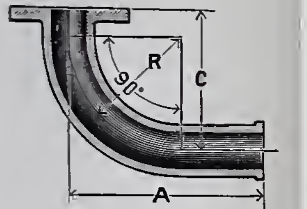


FIG. 2.—Quadrant Bend with Flange.

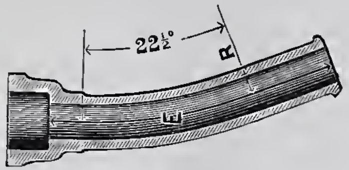


FIG. 3.

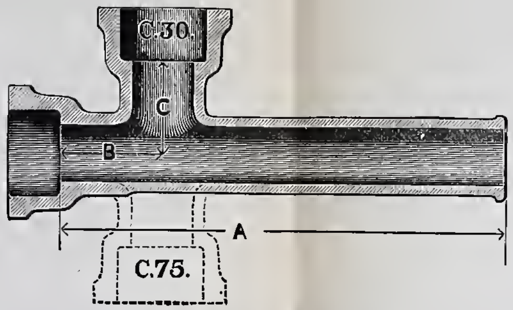


FIG. 4.—T-piece with Sockets.

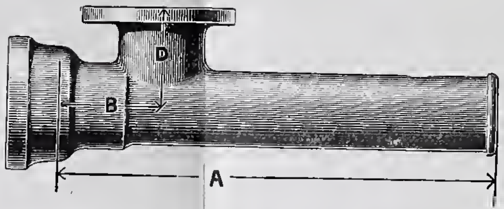


FIG. 5.—T-piece with Socket and Flange.

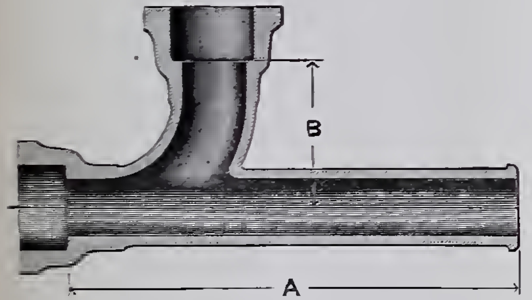


FIG. 6.—T-piece with Sockets and Curve.

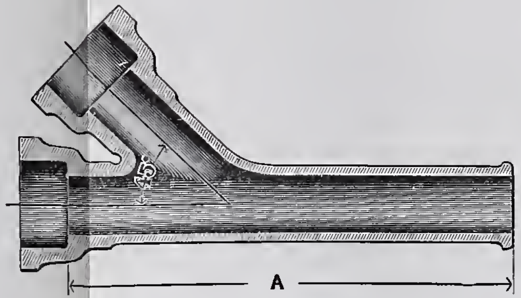


FIG. 7.—Y-piece with Sockets.

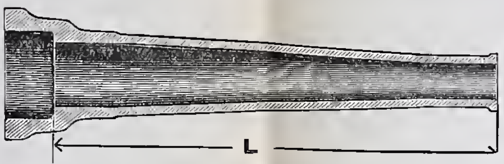


FIG. 8.—Taper-piece.

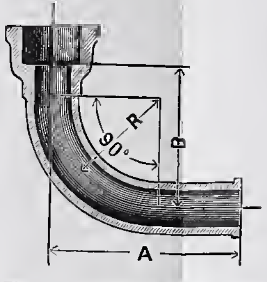


FIG. 9.—Quadrant Bend with Socket.

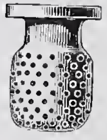


FIG. 10.—Rose-piece.

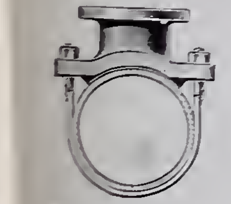


FIG. 11.—Saddle-piece.

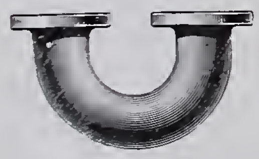


FIG. 12.

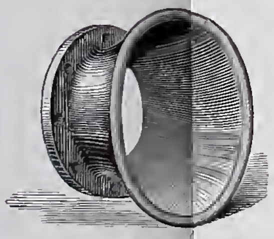


FIG. 13.—Bell Mouth.

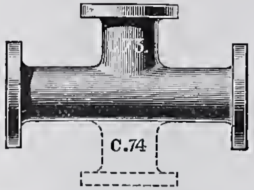


FIG. 14.—T or Cross-piece with Flanges.

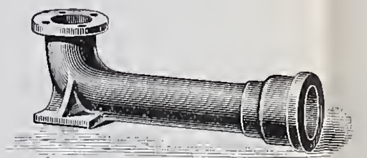


FIG. 15.—Rising Bend.

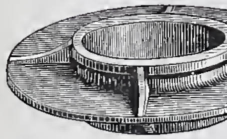


FIG. 16.—Puddle Collar (Single).

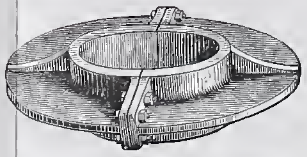


FIG. 17.—Puddle Collar (Double).

SPECIAL BENDS AND OTHER CASTINGS USUALLY KEPT IN STOCK.

PLATE XXXIII.

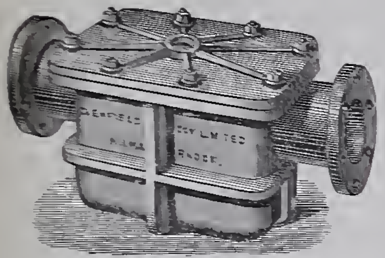


FIG. 18.—Dirt Box.

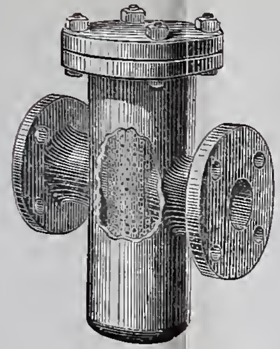


FIG. 19.—Dirt Box.

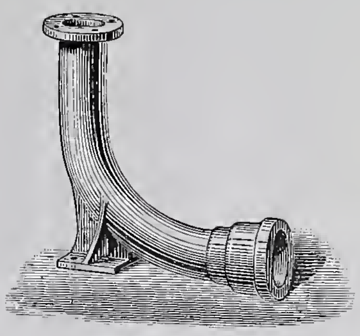


FIG. 20.—Rising Bend.

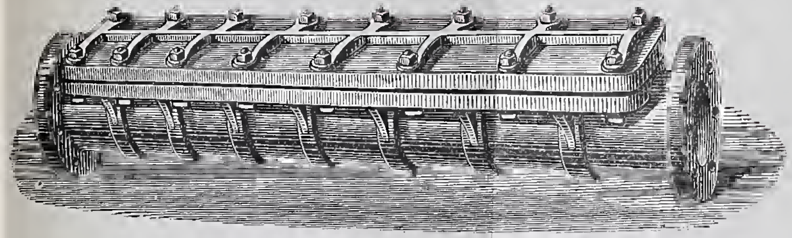


FIG. 21.—Hatch Box.

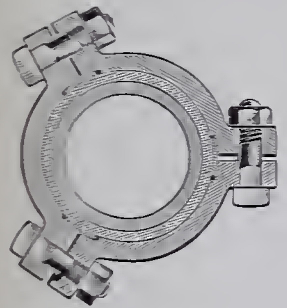


FIG. 22.—Collar.

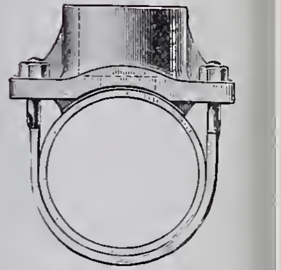


FIG. 23.—Saddle-piece (Cross-section).

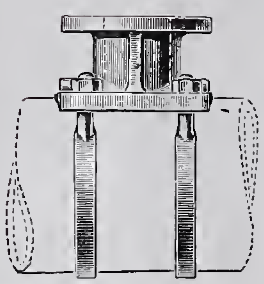


FIG. 24.—Saddle-piece (Side Elevation).

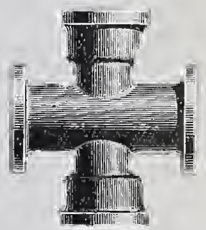


FIG. 25.—Cross-piece.

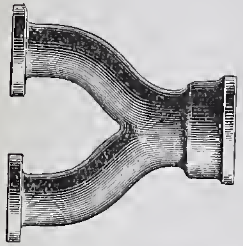


FIG. 26.—Bifurcating-piece.

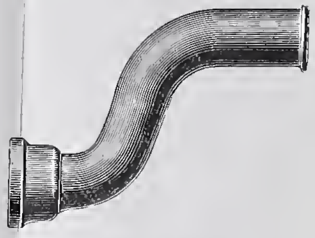


FIG. 27.—S-piece.

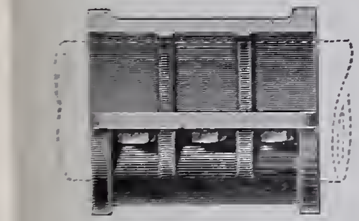


FIG. 22.—Clip for Repair of Burst Pipe.

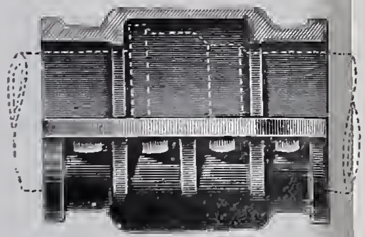


FIG. 29.—Clip for Repair of Pipe at Socket.

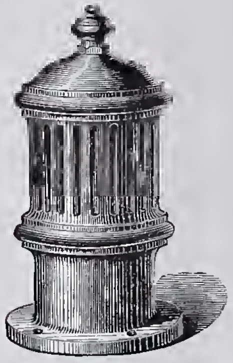


FIG. 30.—Reservoir Ventilator Top.

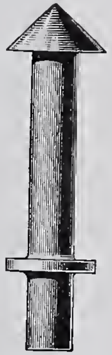


FIG. 31.—Reservoir Ventilator.

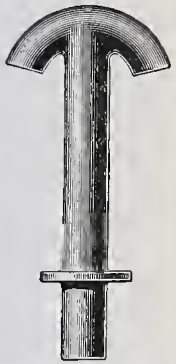


FIG. 32.—Reservoir Ventilator.

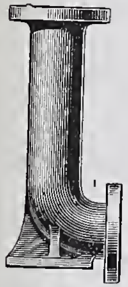


FIG 33.—Rising Bend.

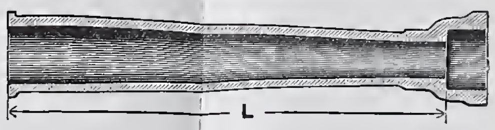


FIG. 34.—Taper-piece.

PIPE TESTING MACHINE.

PLATE XXXIV.

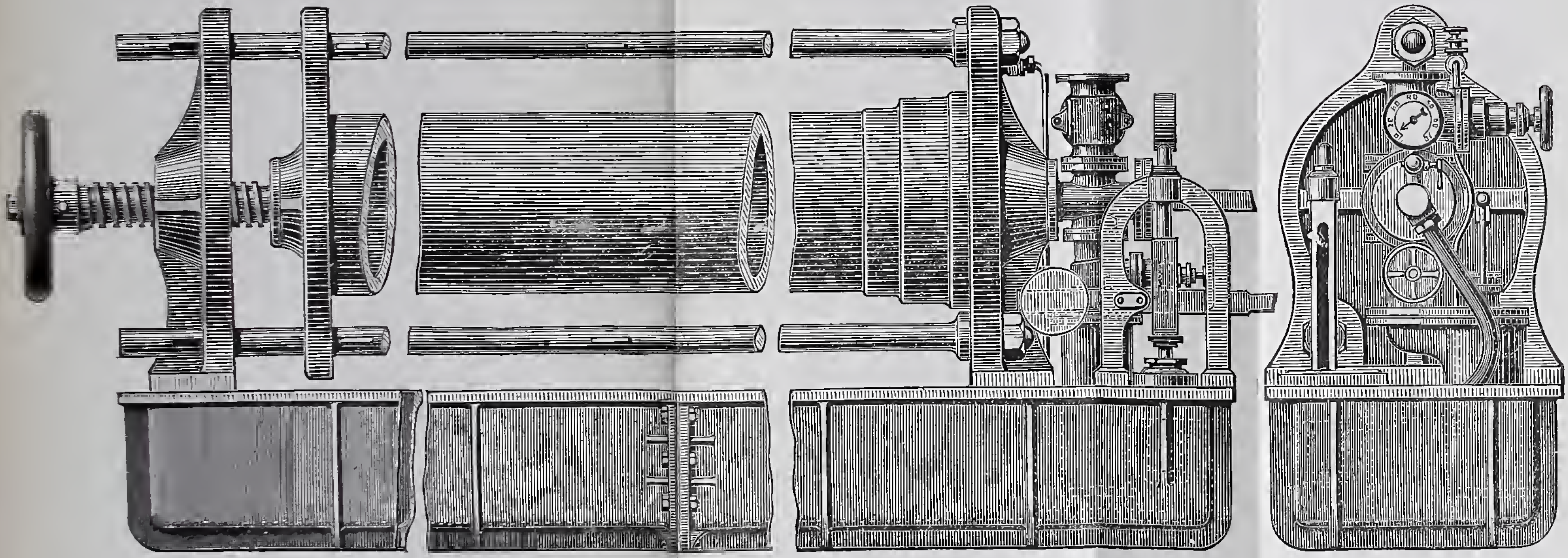
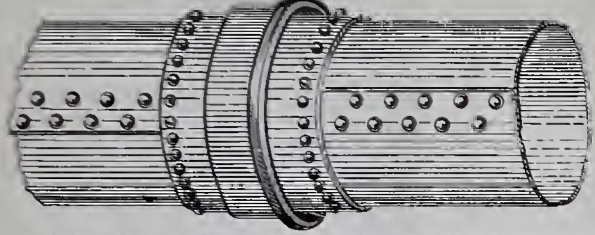
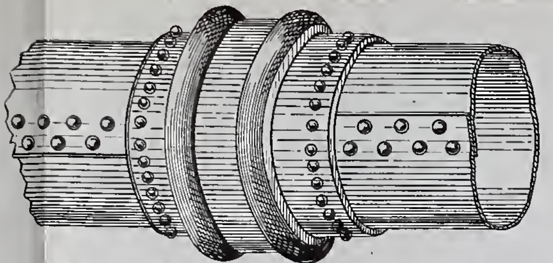
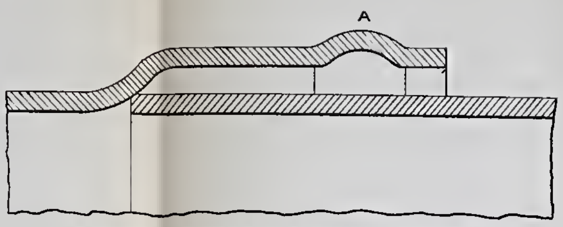


PLATE XXXV.

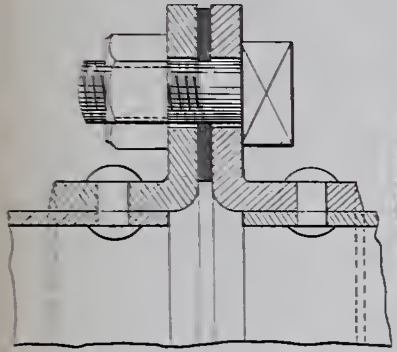
JOINTS IN STEEL PIPES.

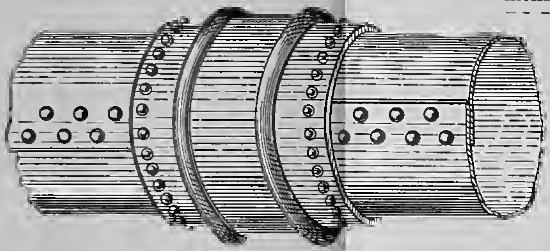

THE RILEY PATENT STAMPED STEEL SOCKET.

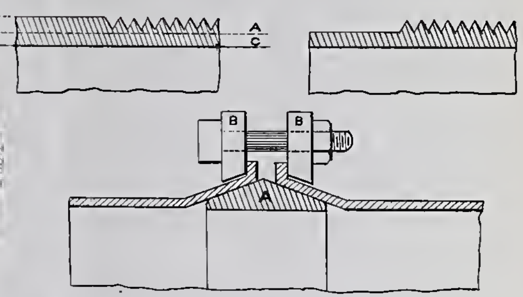

THE CONVERSE PATENT LOCK JOINT.

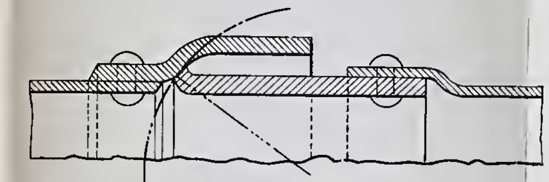


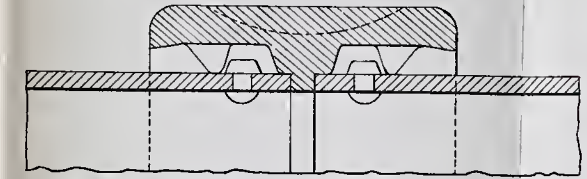
SCHULZ' PATENT SOCKET JOINT

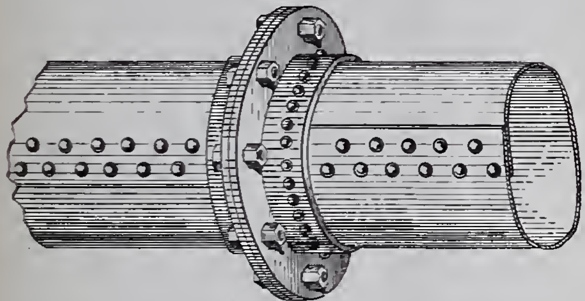

STAMPED STEEL FLANGED JOINT.

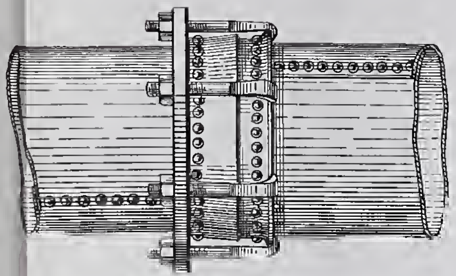

THE STEEL SLEEVE JOINT.

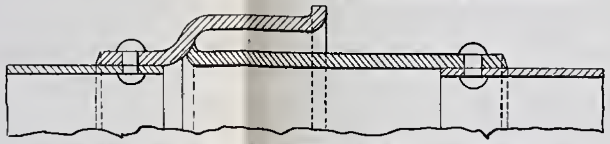


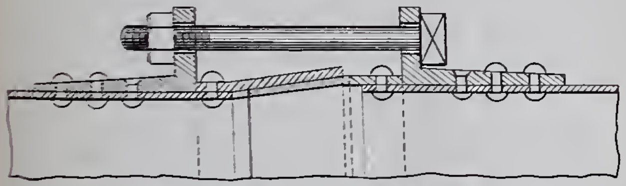

DUNCAN PATENT SOCKET JOINT WITH SPHERICAL BEARING FOR SPIGOT.

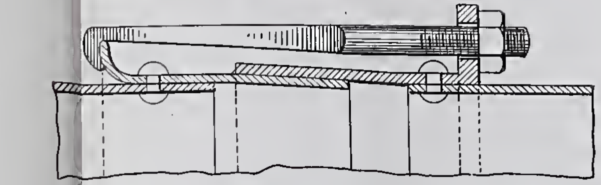

THE CONVERSE PATENT LOCK JOINT.

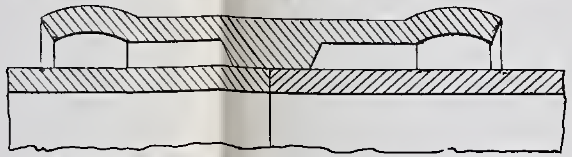

THE FLANGED JOINT.

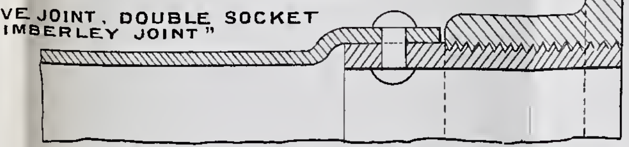

THE BROWN PATENT JOINT.


THE RILEY PATENT STAMPED STEEL SOCKET AND WELDED SPIGOT.


THE BOURNEMOUTH PIPE JOINT.

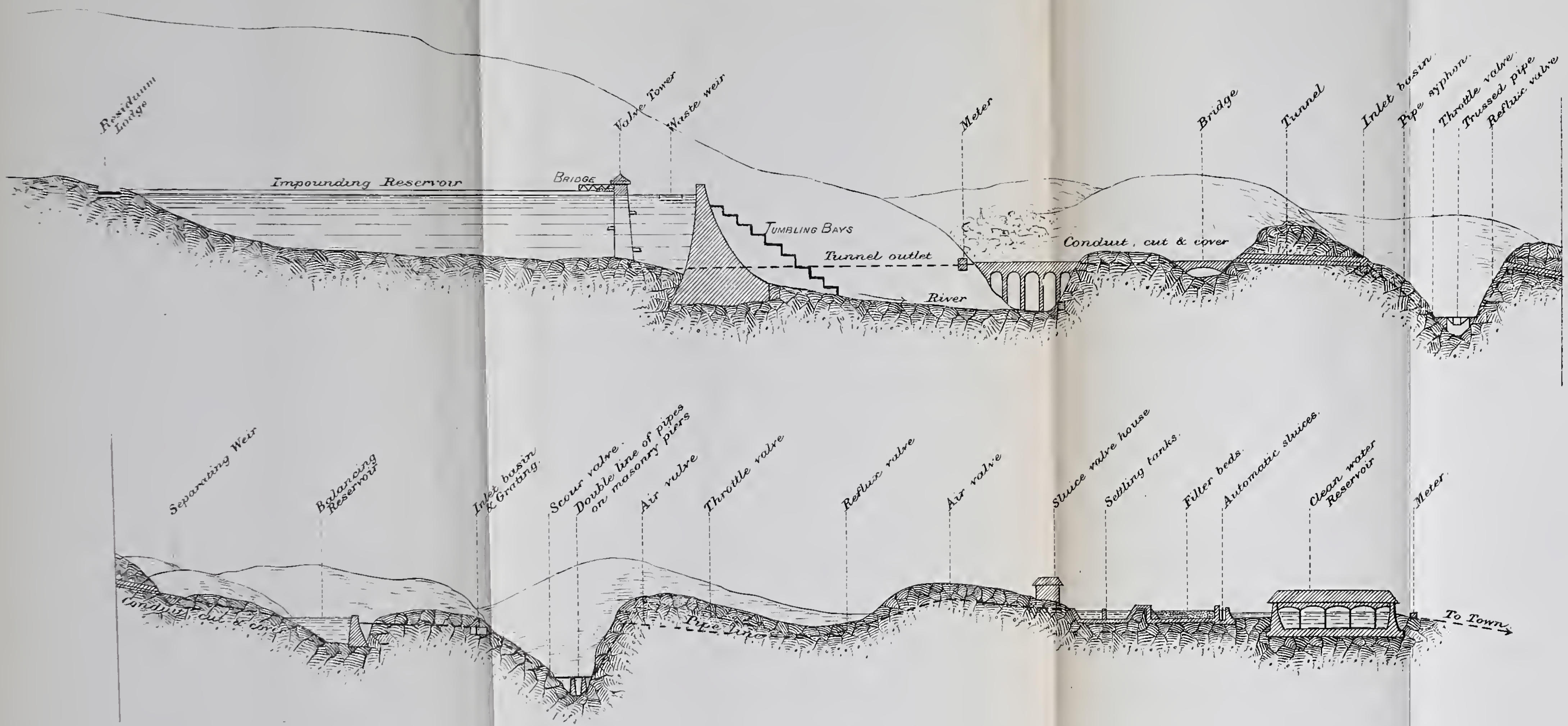

BROWN PATENT CONICAL JOINT.


STEEL SLEEVE JOINT, DOUBLE SOCKET "THE KIMBERLEY JOINT"


FLANGED JOINT WITH SCREWED WELDED SPIGOT.

TYPICAL SECTION OF AQUEDUCT.

PLATE XXXVI.



THE DIURNAL SOFTENER.

ANDREW HOWATSON'S PATENT.

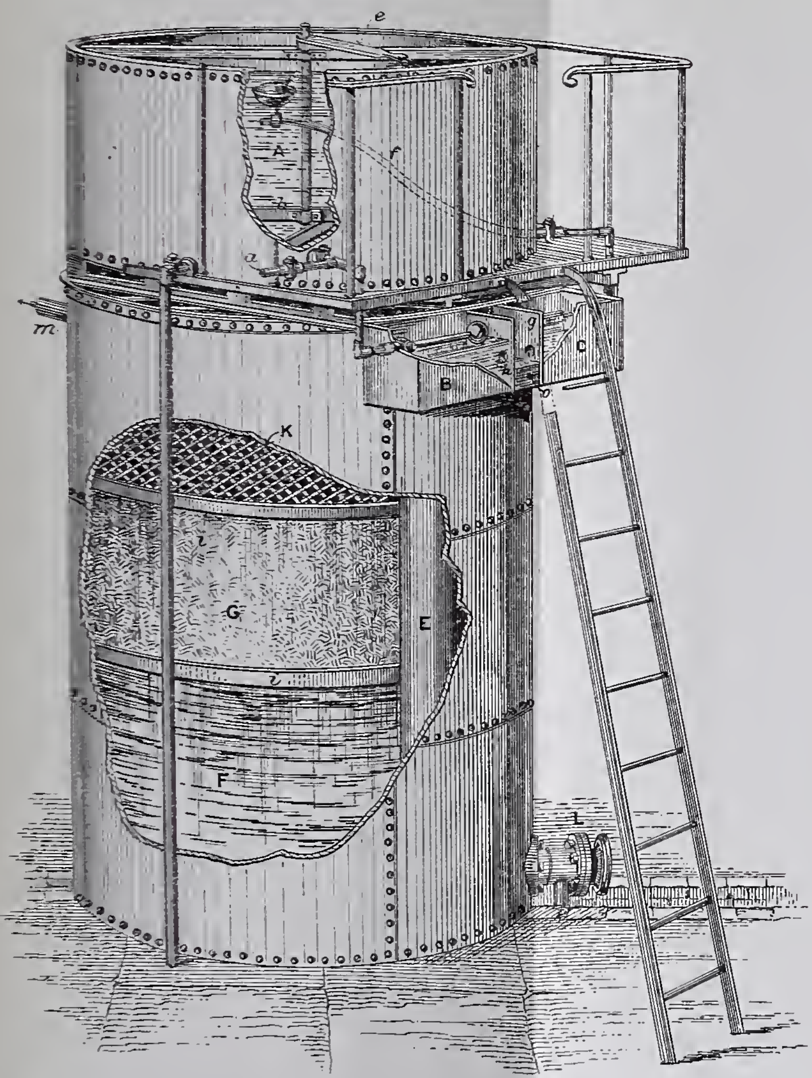
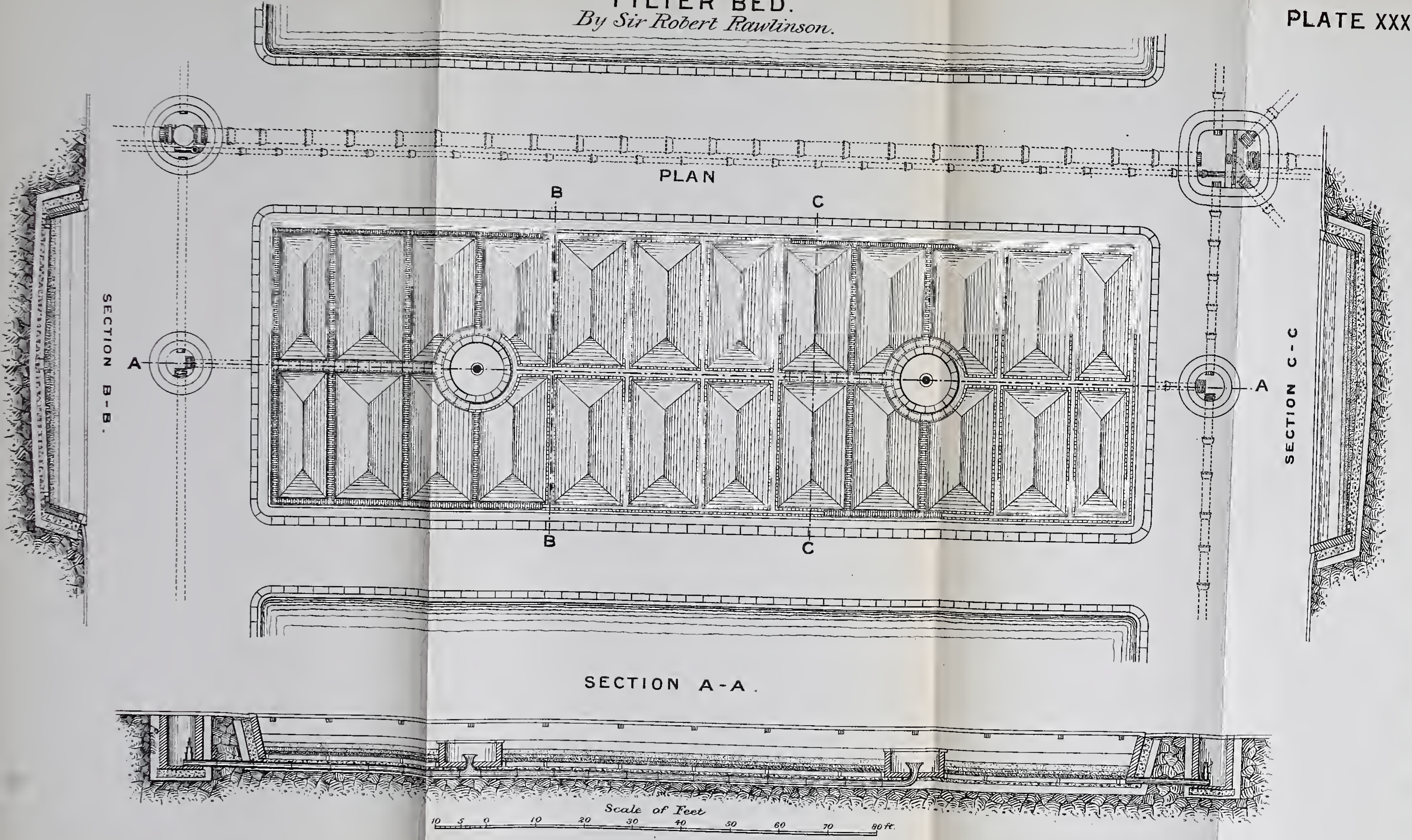


PLATE XXXVIII.

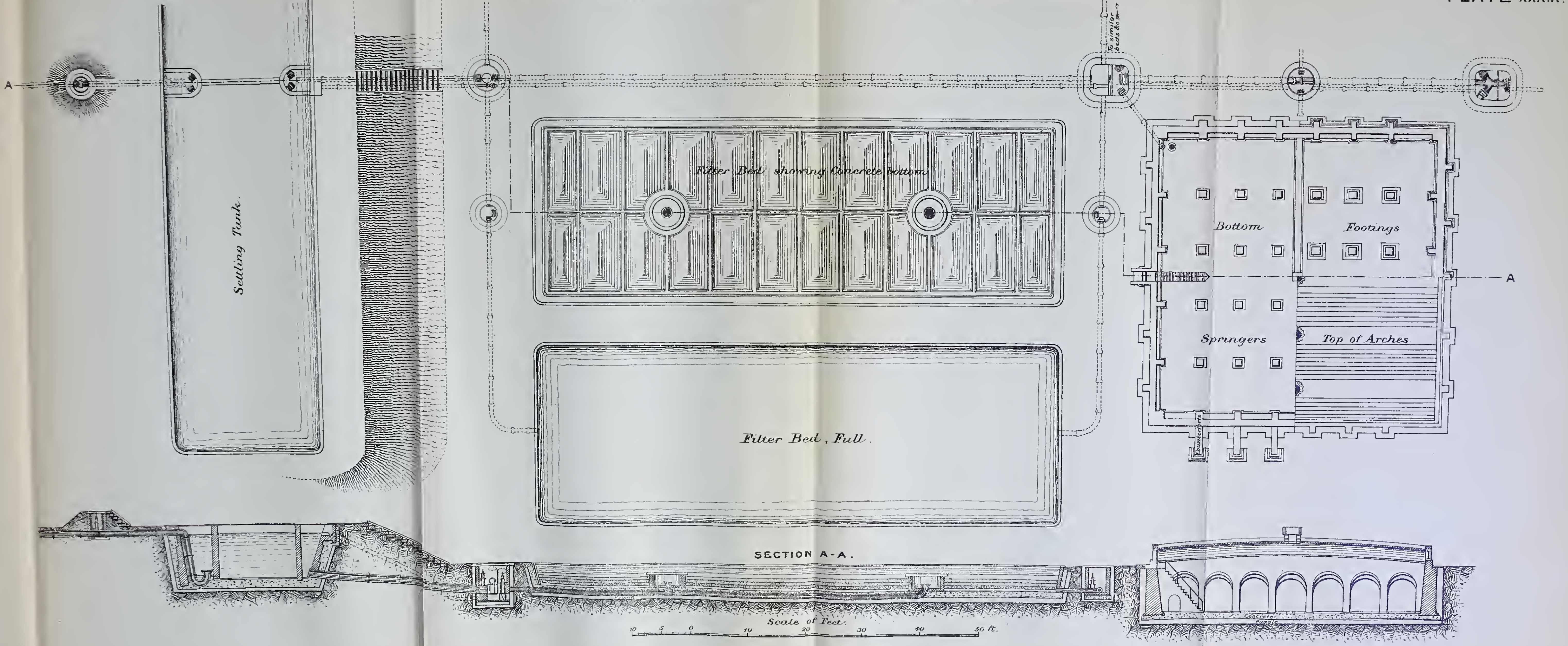
FILTER BED.

By Sir Robert Rawlinson.



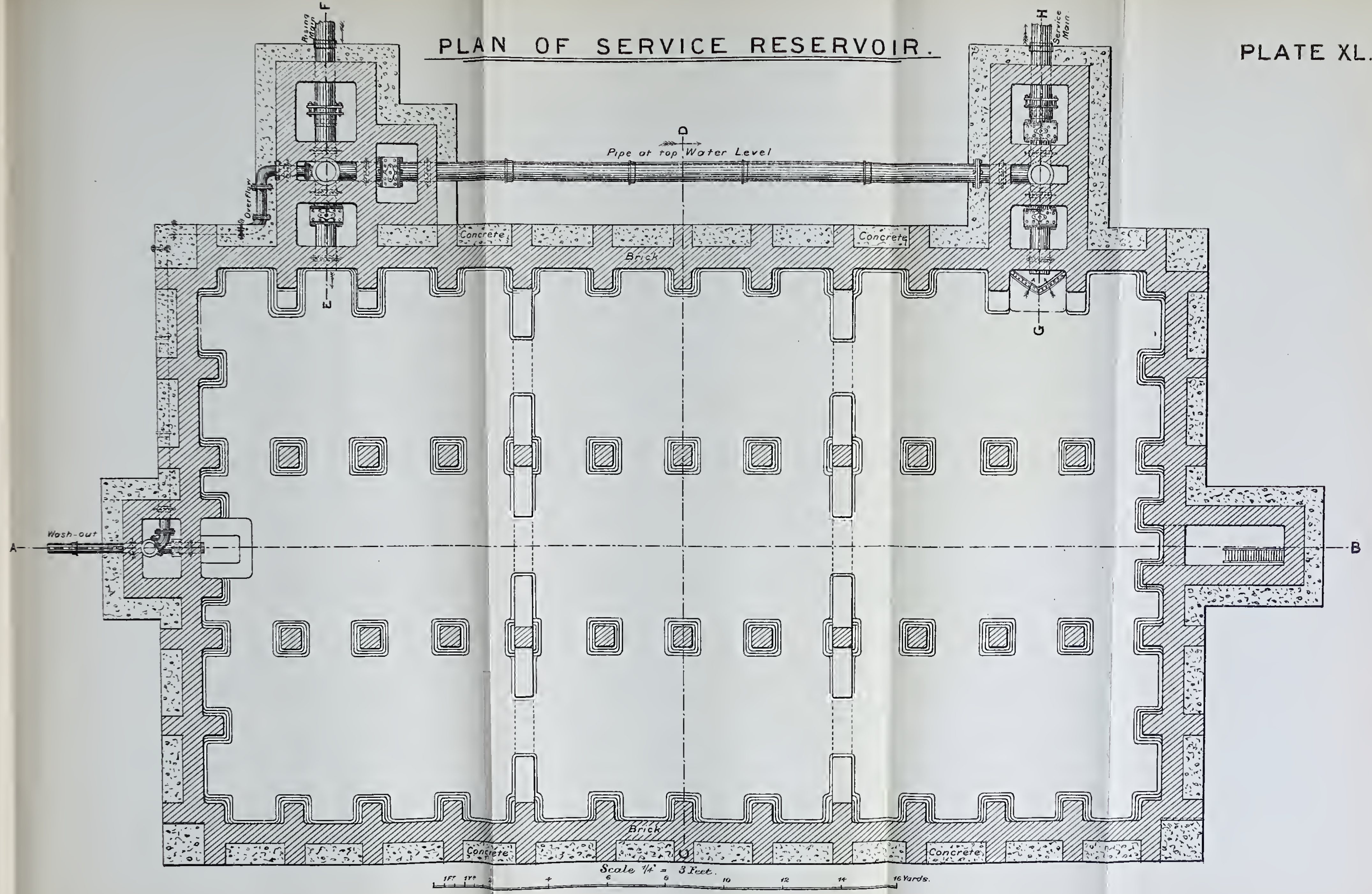
SETTLING TANKS, FILTER BEDS & SERVICE RESERVOIR.

PLATE XXXIX.



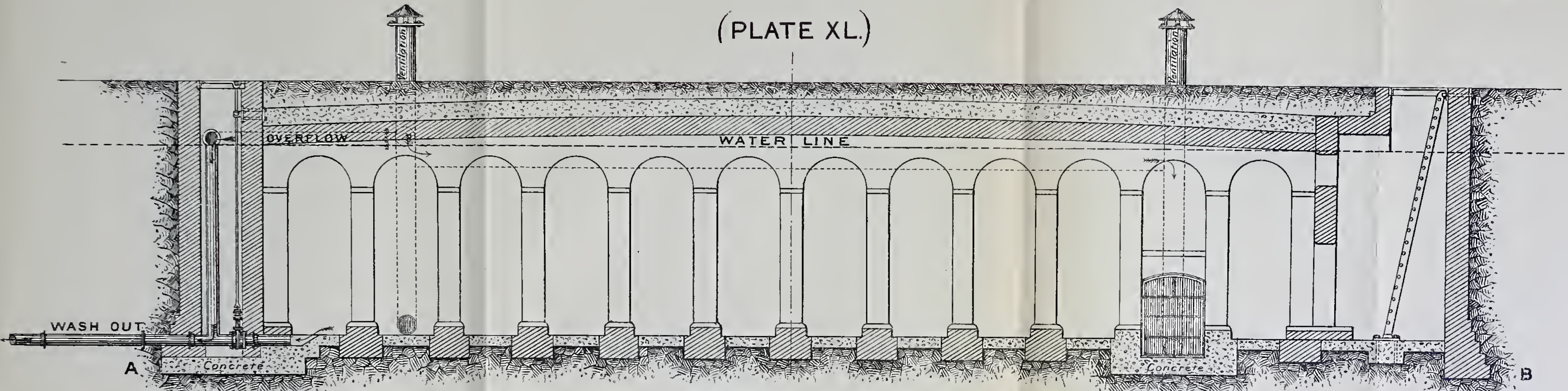
PLAN OF SERVICE RESERVOIR.

PLATE XL.

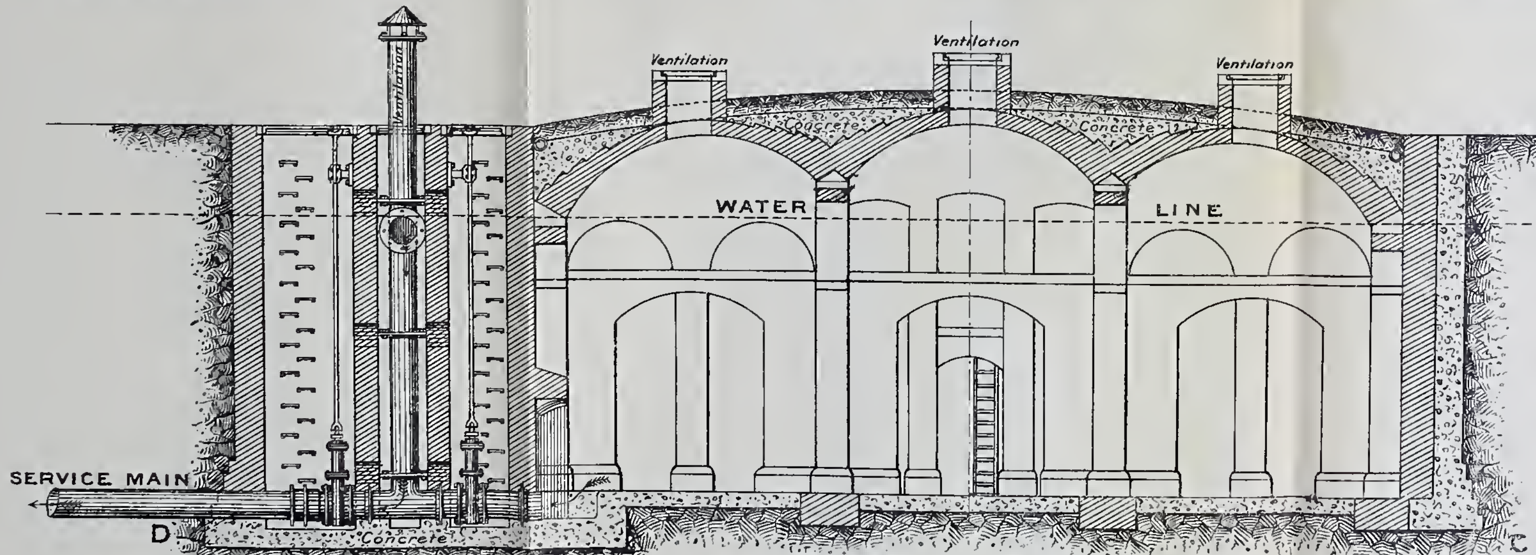


SECTIONS OF SERVICE RESERVOIR.

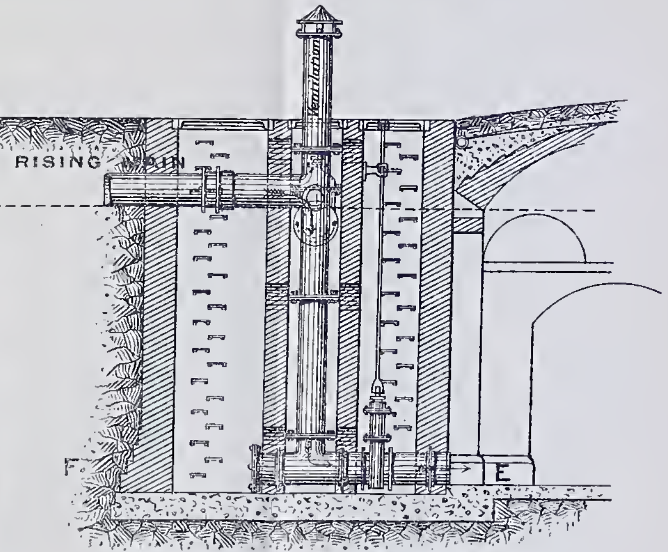
(PLATE XL.)



SECTION ON A-B.



SECTION ON C-D.



SECTION OF INLET WELL E-F.

Scale 1/4" = 3 *Feet.*

1 FT 1 YD 2 4 6 8 10 12 14 16 YARDS.

CAST-IRON TANK.

PLATE XLI.

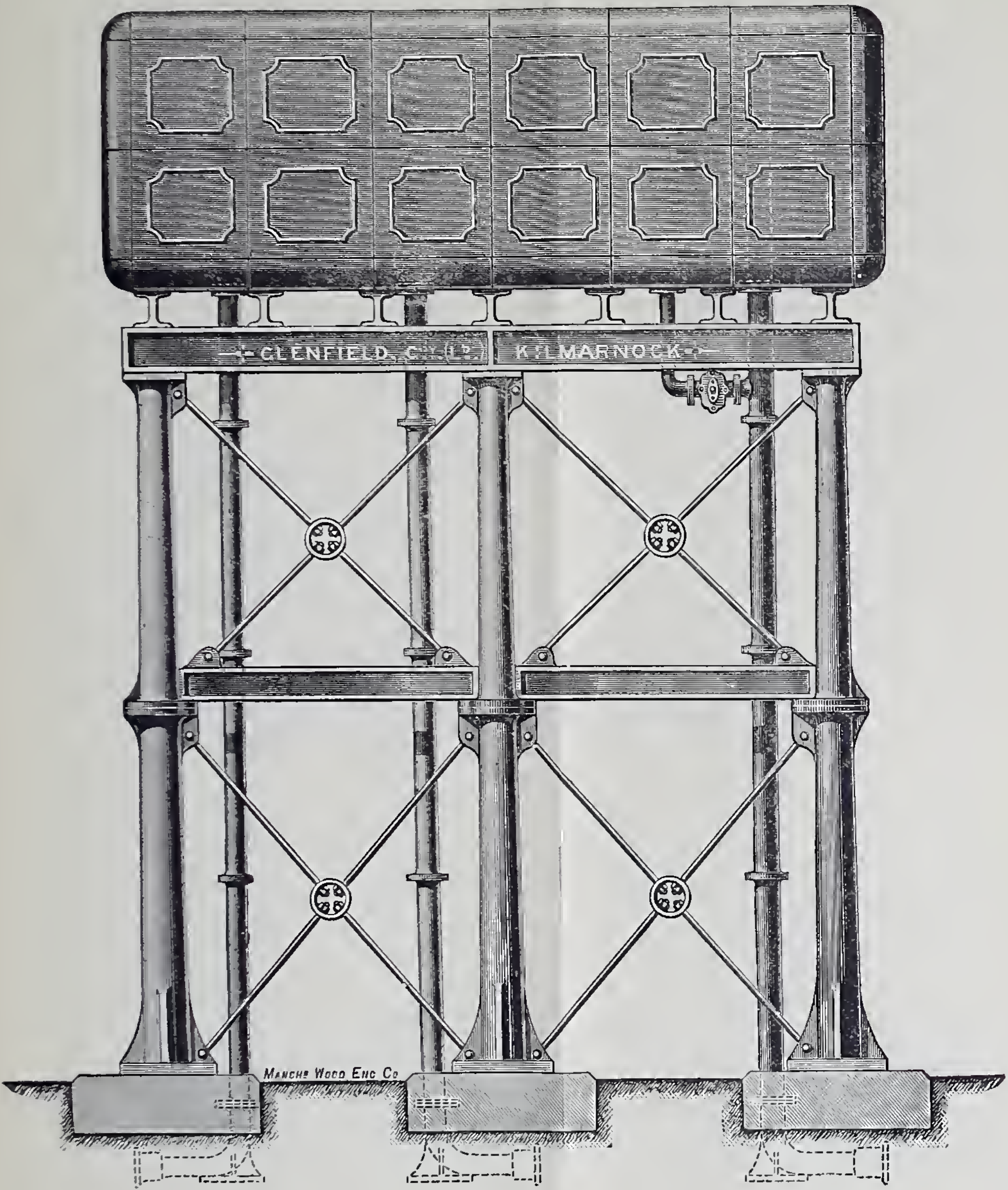
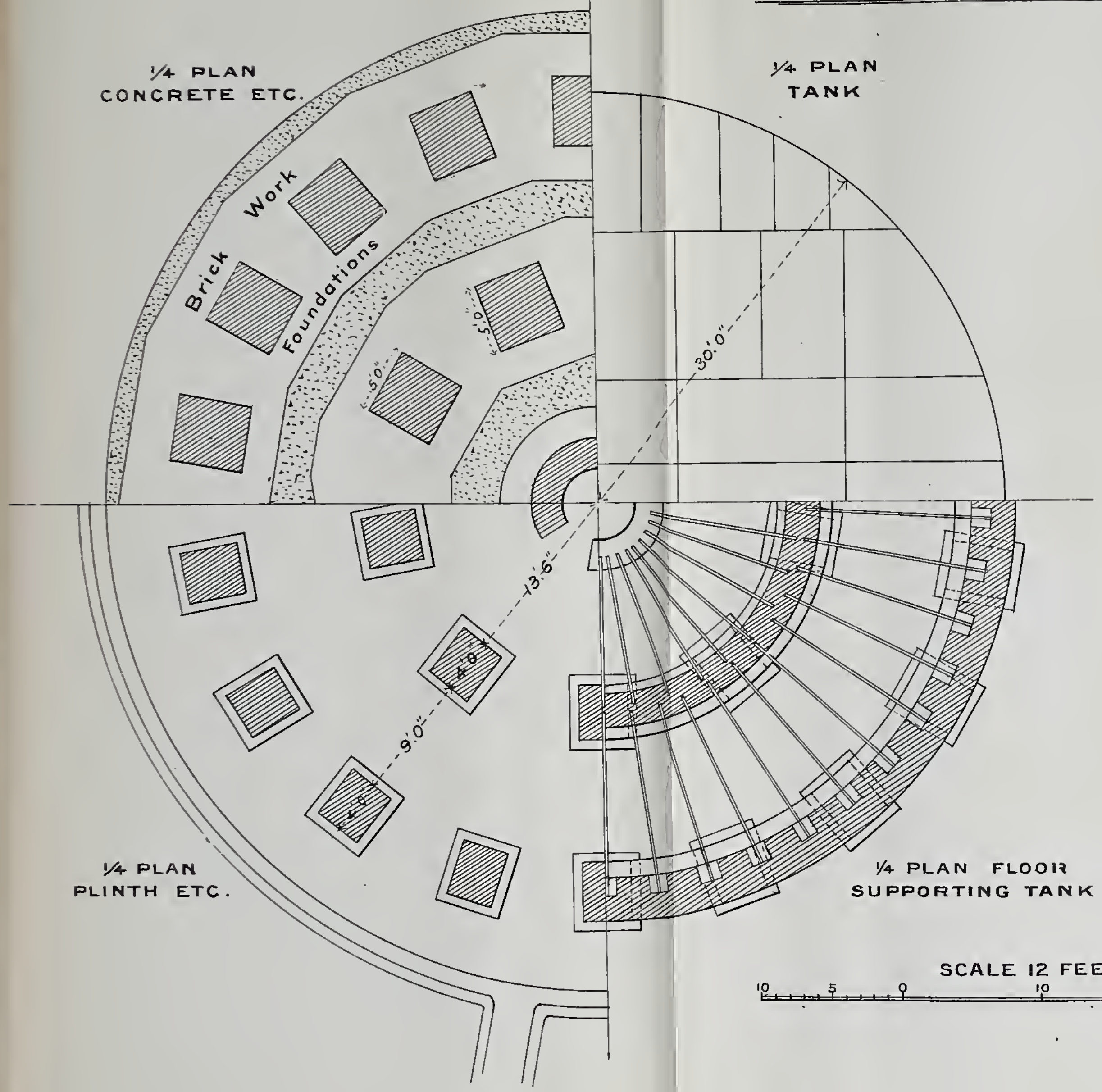
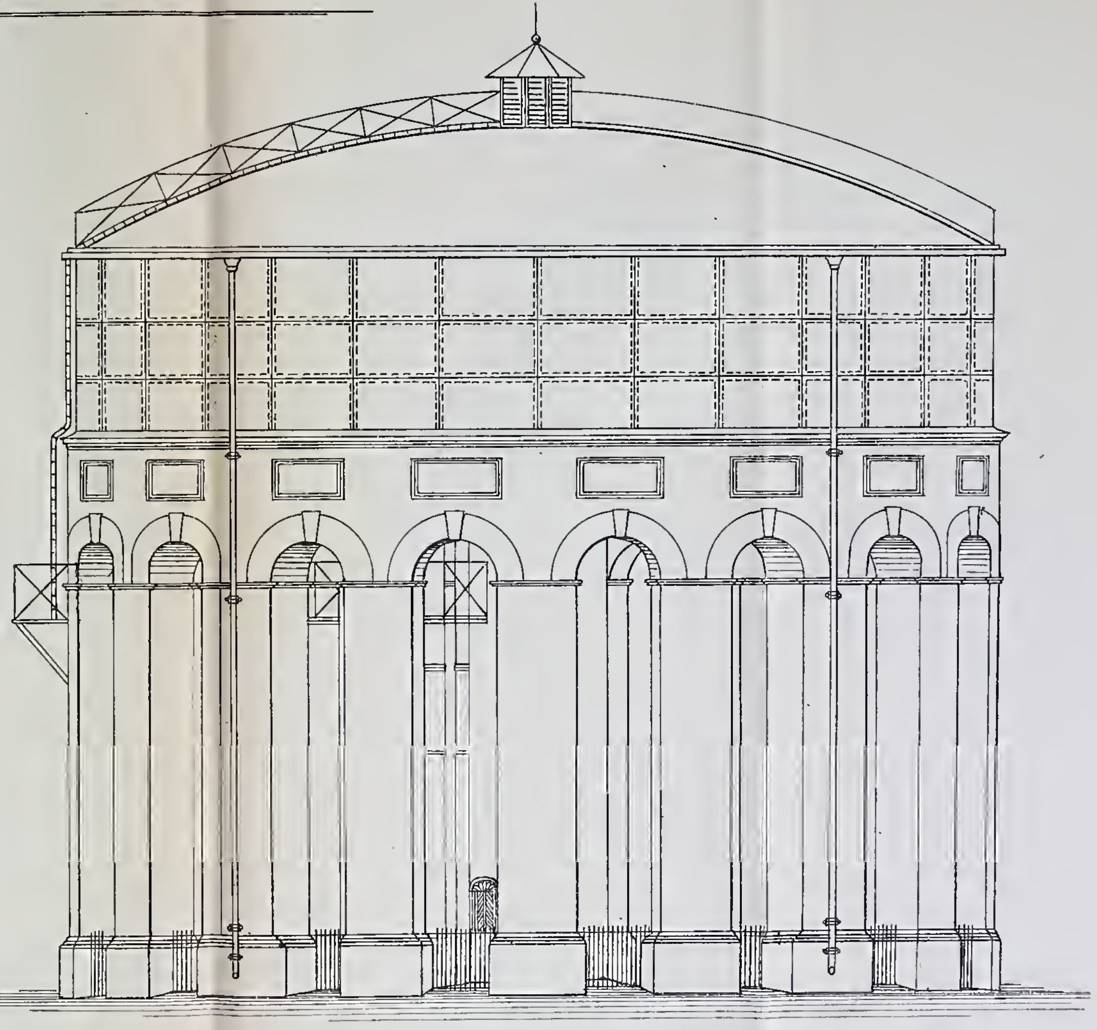


PLATE XLII.

NEW CANTONMENT WATER SUPPLY,-ALLAHABAD.

RAISED RESERVOIR 60 FT DIAMETER.



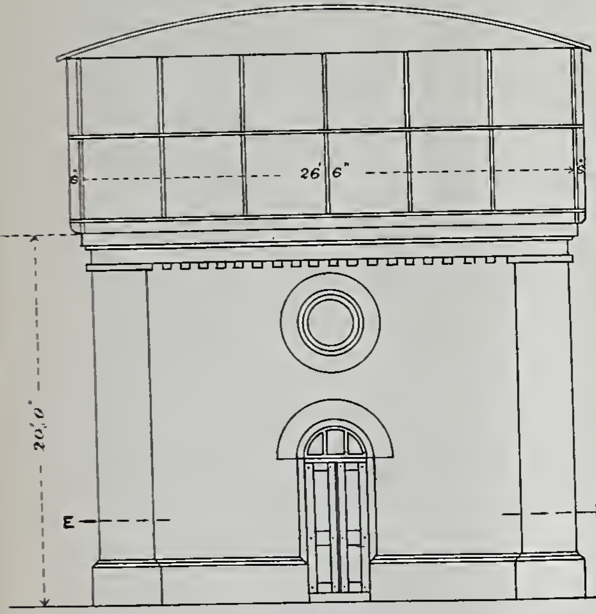


SCALE 12 FEET TO AN INCH.

FIRE RESERVE TANK OR WATER TOWER.

THAMES DISTRICT - CHATHAM.

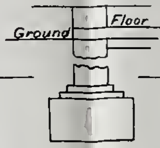
PLATE XLIII.

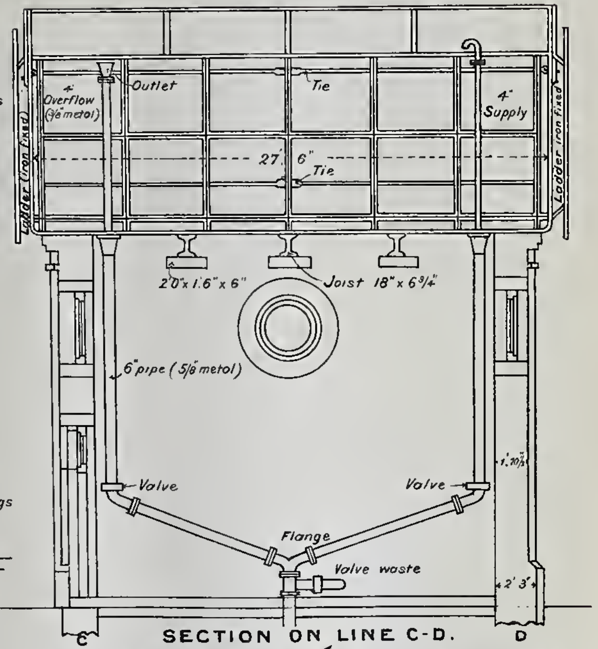


ELEVATION.

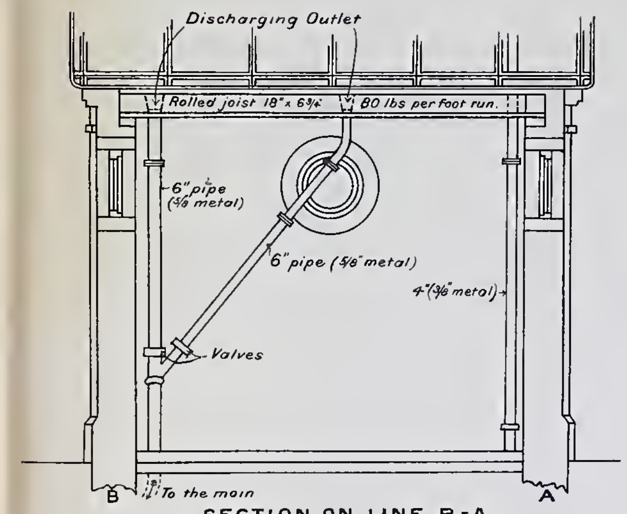
The level of the Dividing partitions to be the same as sides of tank 9.6" but each partition is to have a slot 3" x 1¼" at a height of 9.3" from bottom of tank to allow water to flow from one to another.

Section of Footings at A. B. C & D.

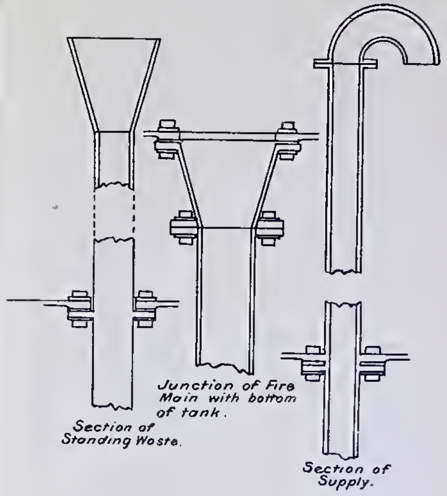




SECTION ON LINE C-D.



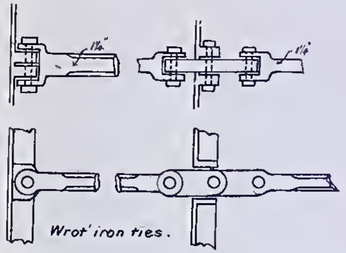
SECTION ON LINE B-A.



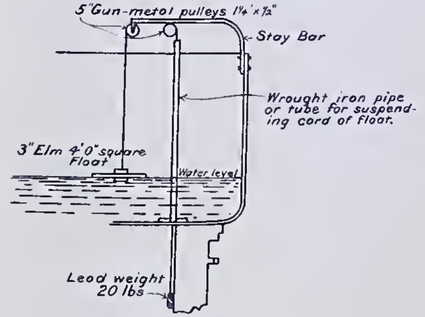
Section of Standing Waste.

Junction of Fire Main with bottom of tank.

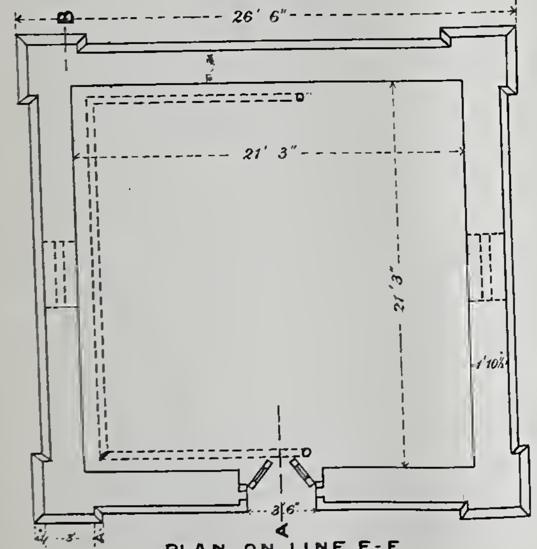
Section of Supply.



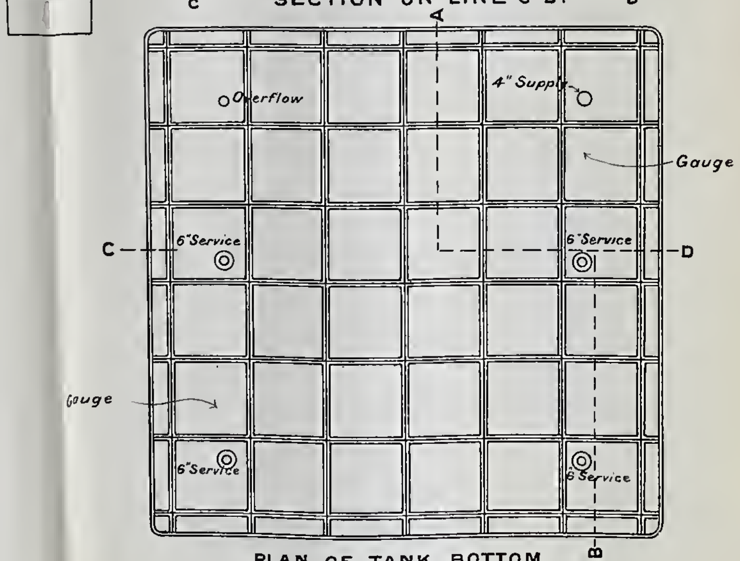
Wrot' iron ties.


5" Gun-metal pulleys 1¼" x ½"
Stay Bar
Wrought iron pipe or tube for suspending cord of float.
3" Elm 4'0" square Float
Water level
Lead weight 20 lbs

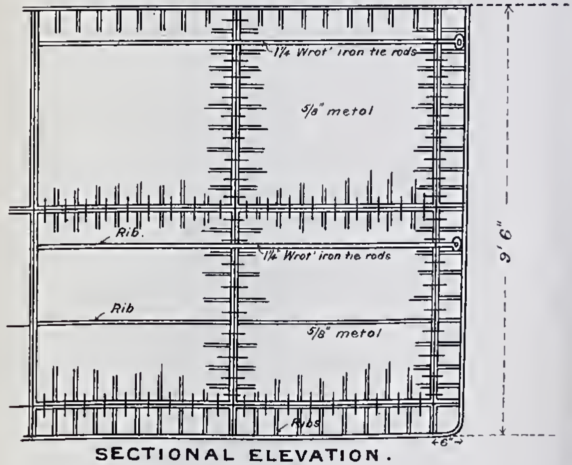
Detail of Telltale.



PLAN ON LINE E-F.



PLAN OF TANK BOTTOM.



SECTIONAL ELEVATION.

Scale ⅛ inch = 1 Foot.

SLUICE VALVES.

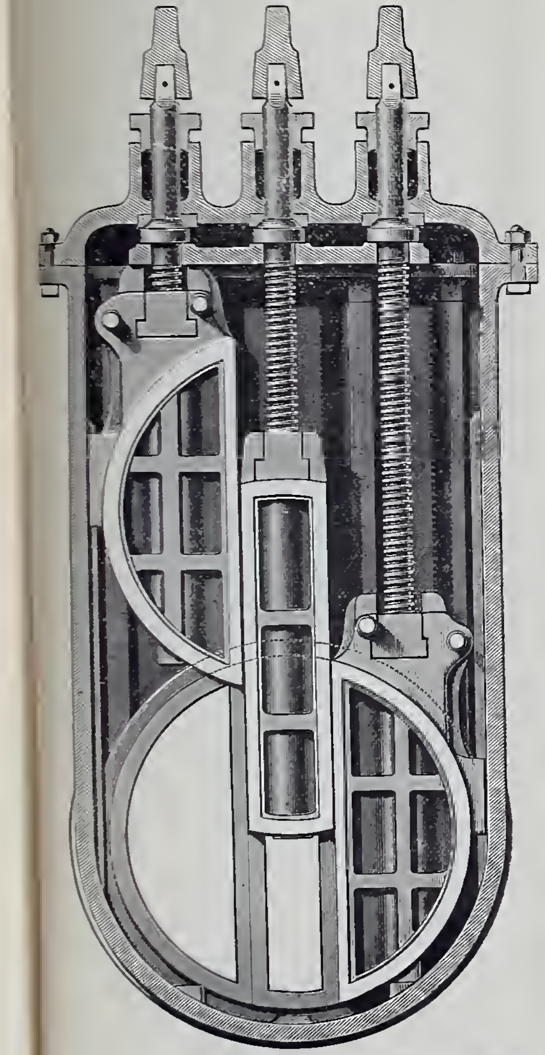


FIG 1.—Transverse Section of Large Valve in 3 pieces

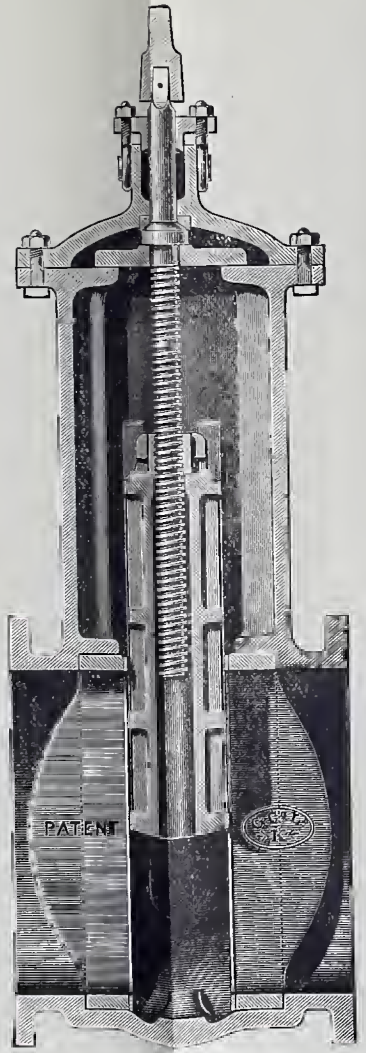


FIG. 2.—Longitudinal Section of Large Valve in 3 pieces.

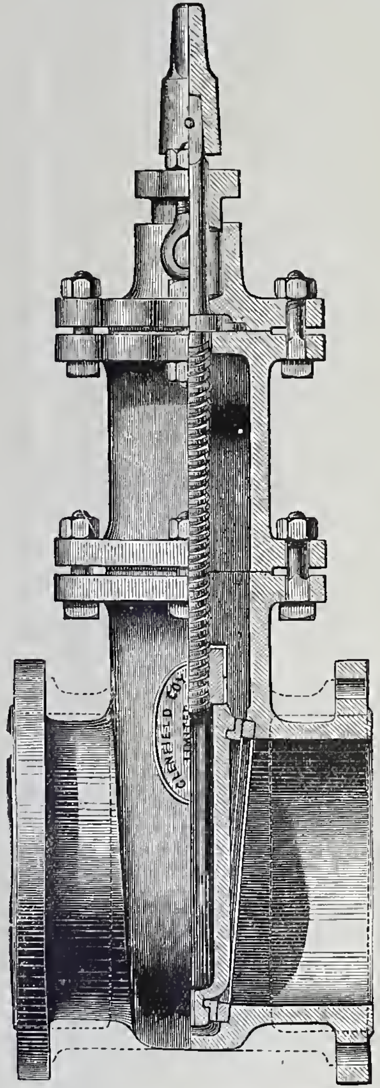


FIG. 3.—Half Section, Half Elevation of Valve, in 1 piece.

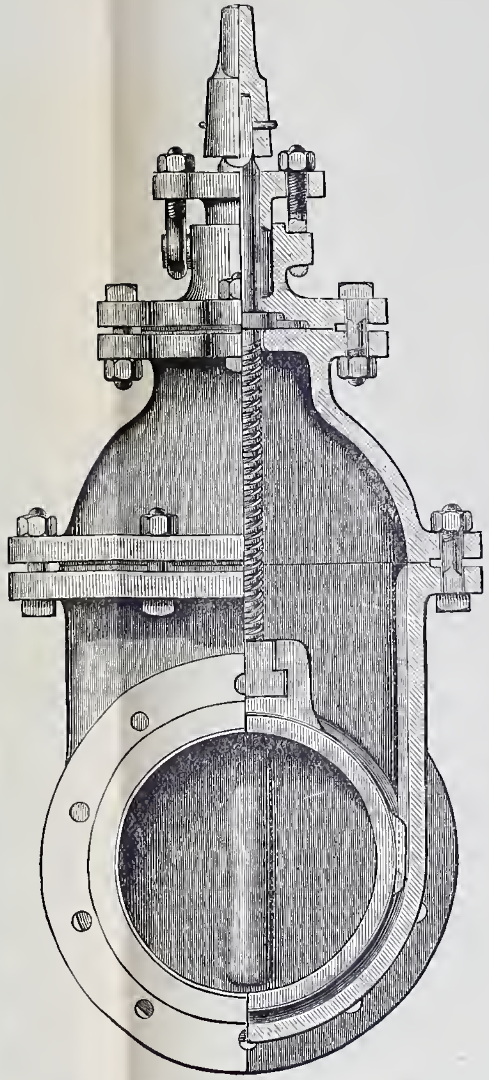


FIG. 4.—Transverse Section of Valve in 1 piece.

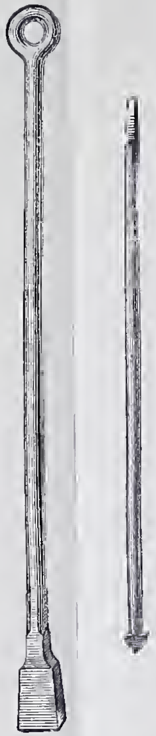


FIG. 5. — Sluice Valve Keys.

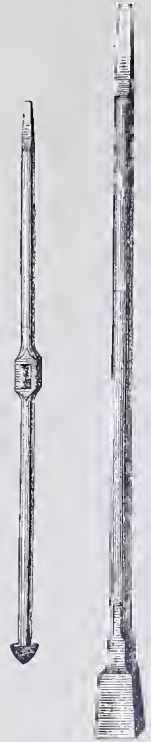


FIG. 6. — Sluice Valve Key and T-rod.

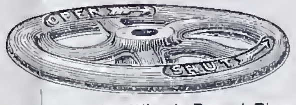


FIG. 7.—Valve Wheel, Round Rim.

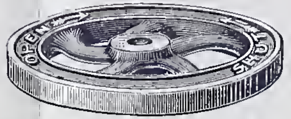


FIG. 8.—Valve Wheel, Square Rim.

THROTTLE VALVES.

PLATE XLV.

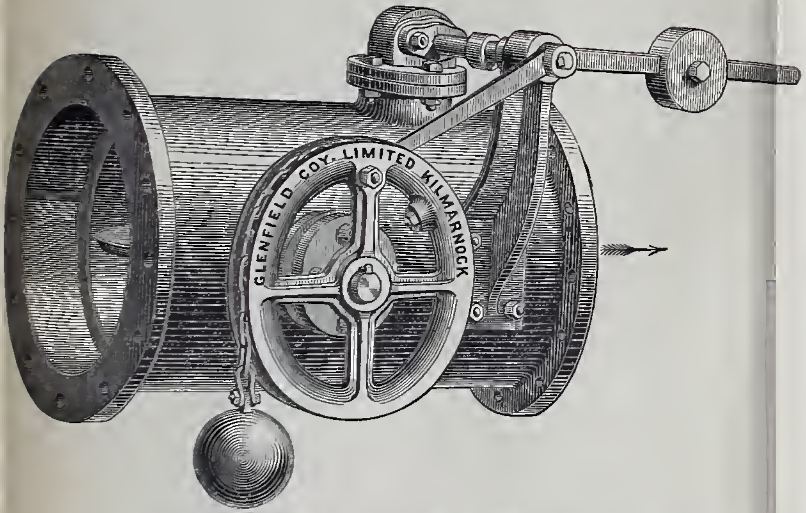


FIG. 1.—For using on a Main, near its source, where quick closing can do no damage.

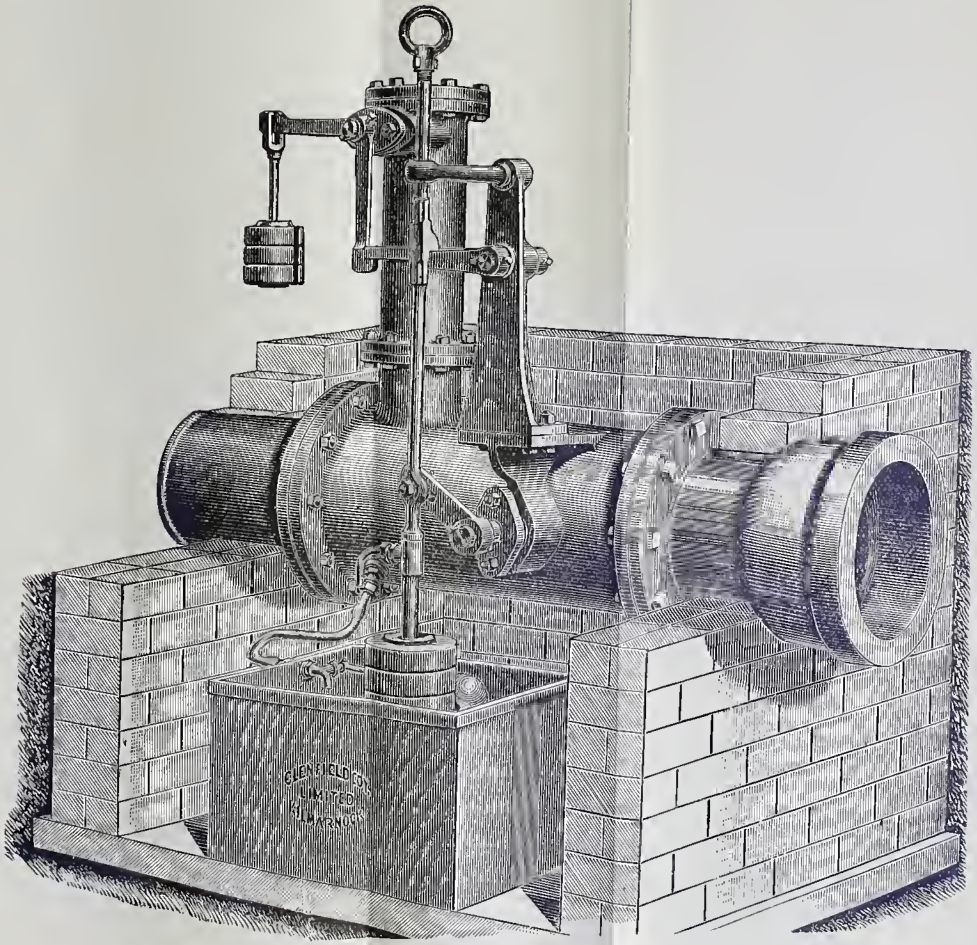


FIG. 2.—Self-acting Valve, arranged to be re-set by hand from the surface of the ground.

APPARATUS FOR TAPPING MAIN PIPES WHEN FULL.

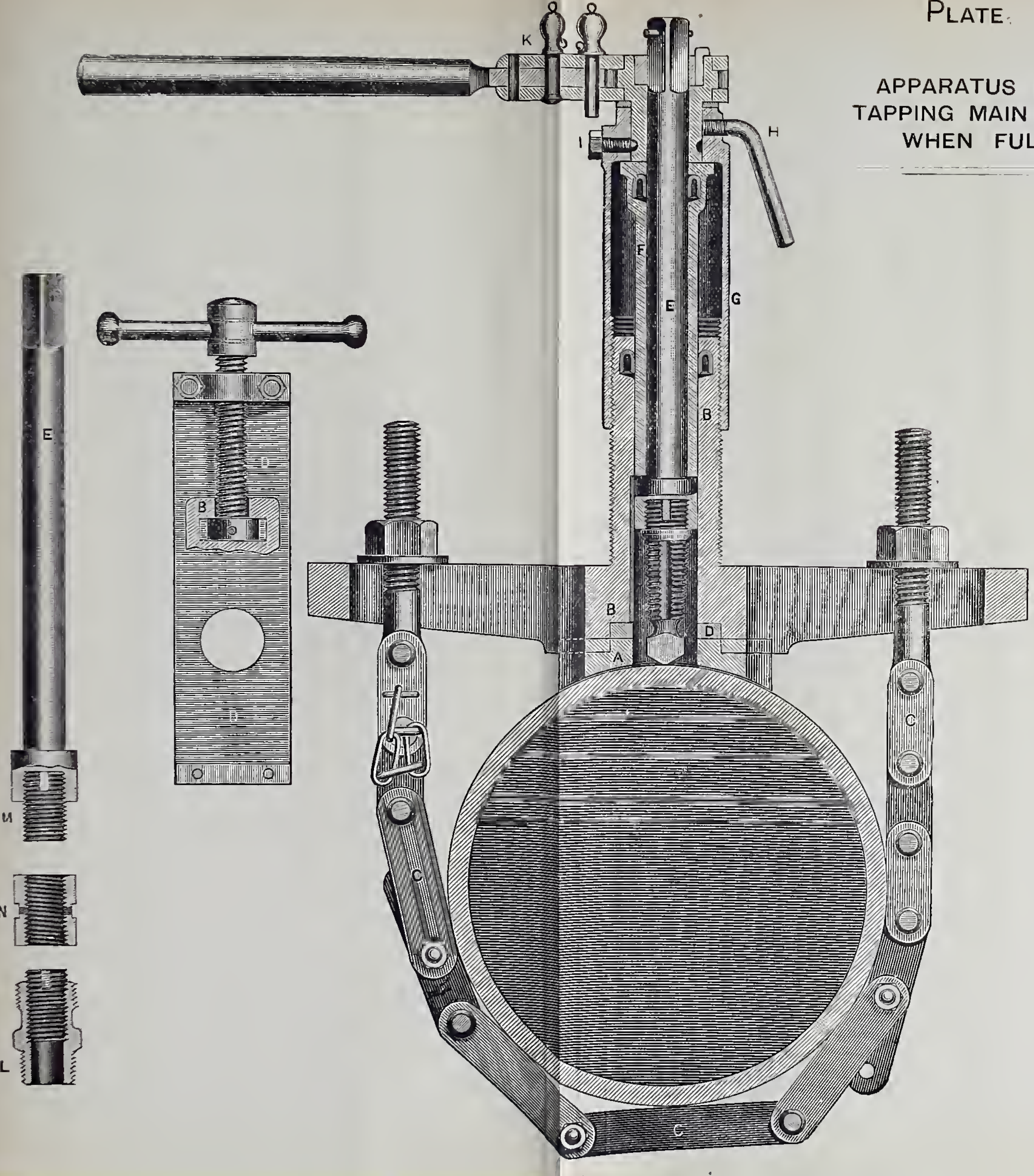
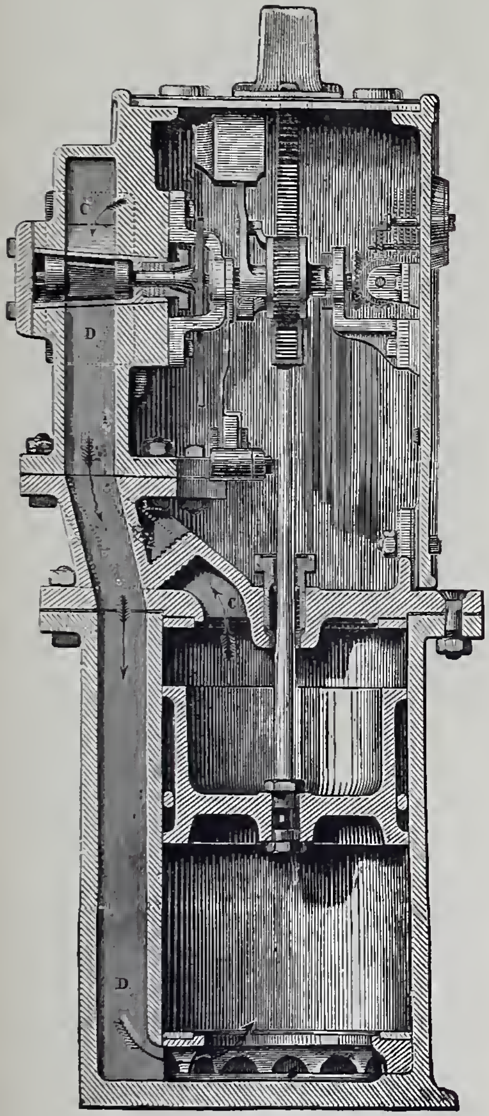
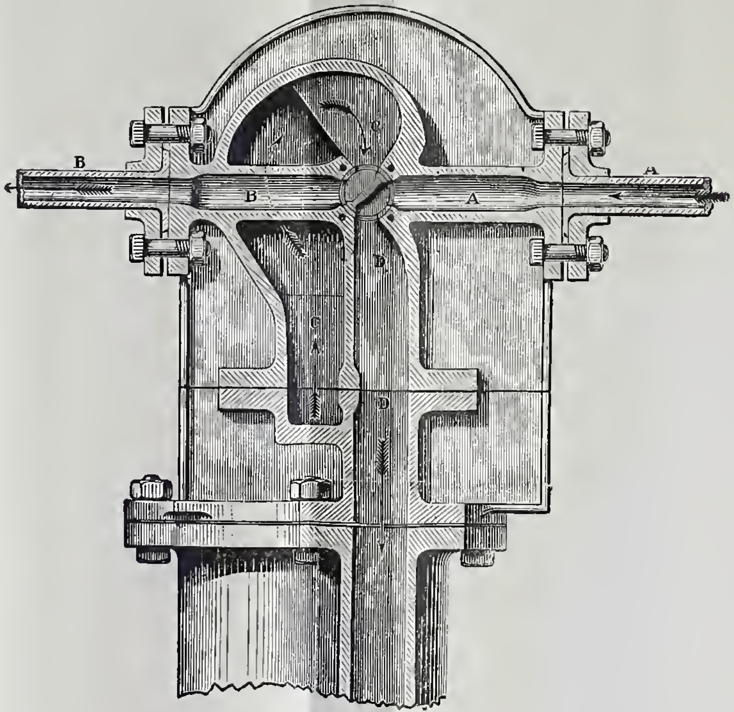


PLATE XLVII.

KENNEDY'S WATER METER.





ENGLISH WATER METERS.

Plate XLVIII.

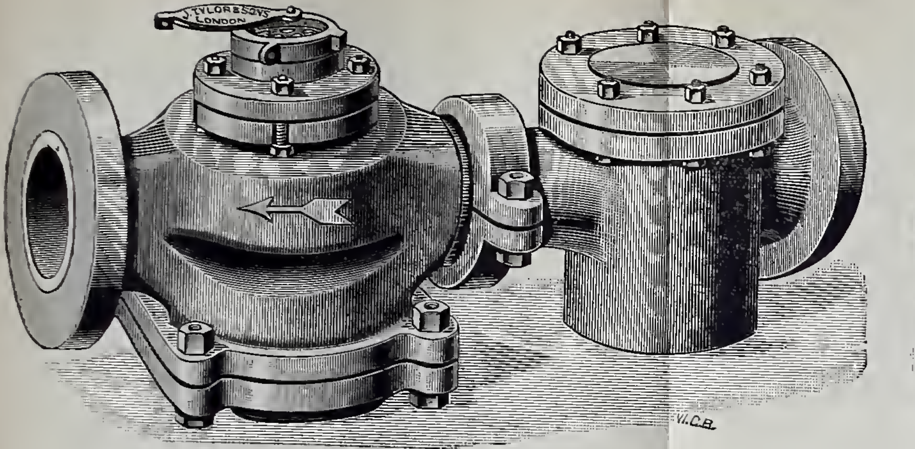


FIG. 1.

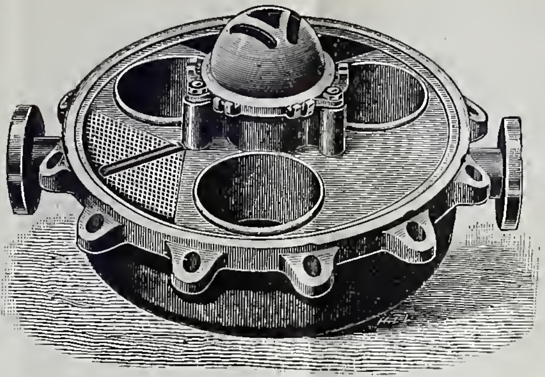


FIG. 2.

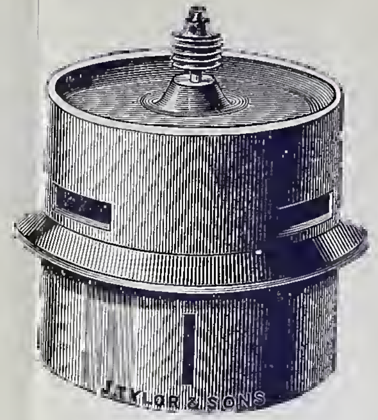


FIG. 3.

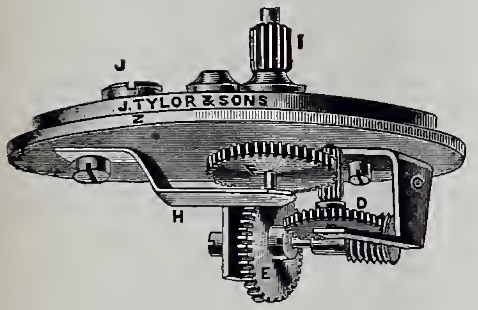


FIG. 4.

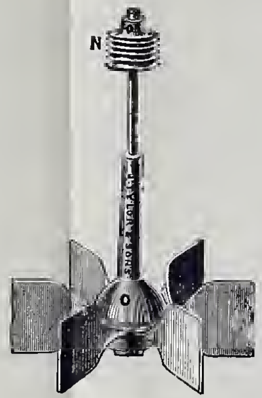


FIG 5.

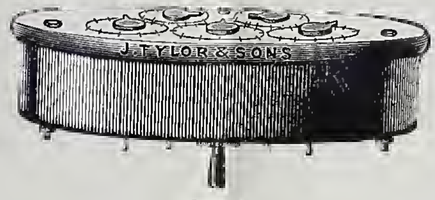


FIG. 6.

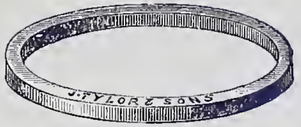


FIG. 7.

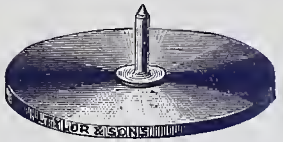


FIG. 8.

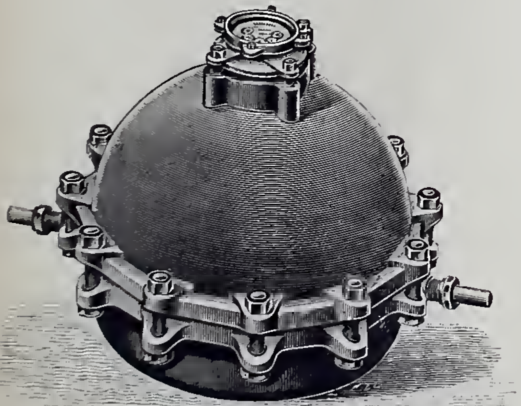


FIG. 9.

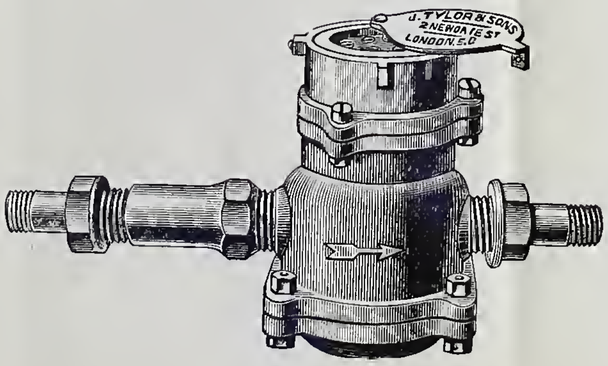


FIG. 10.

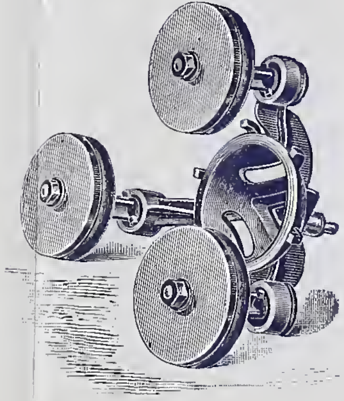
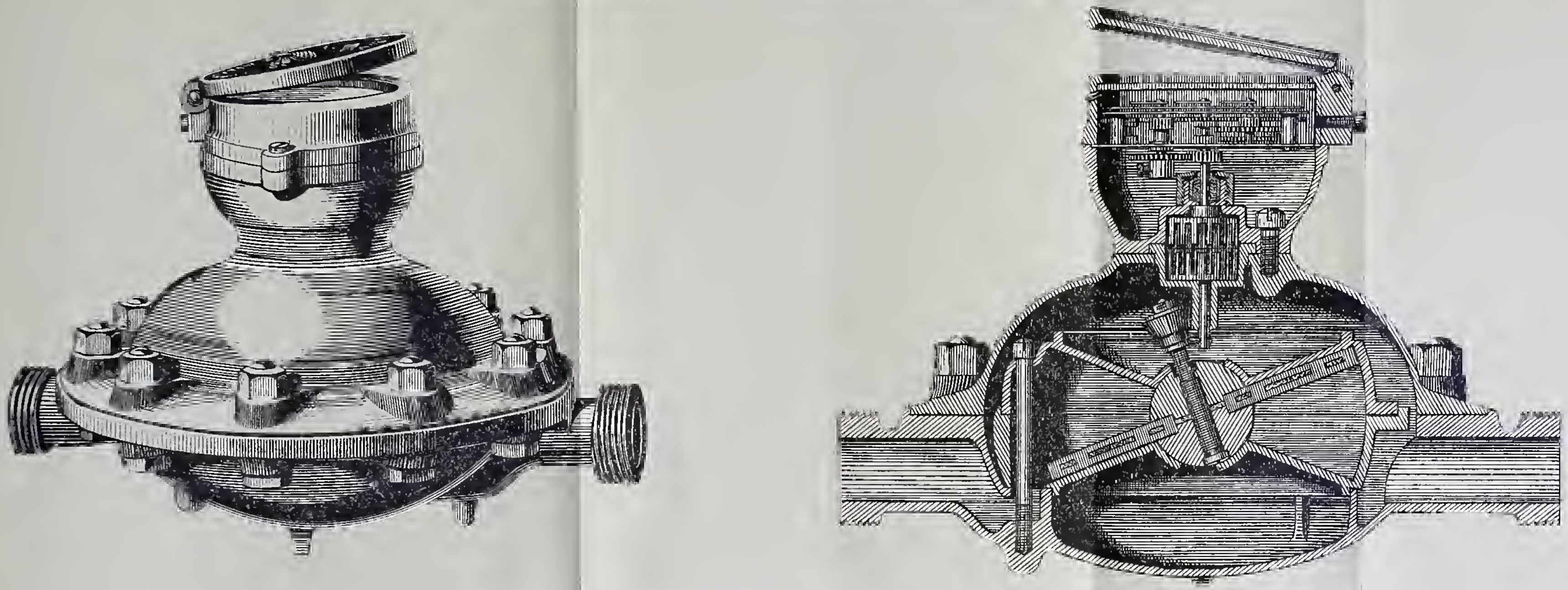


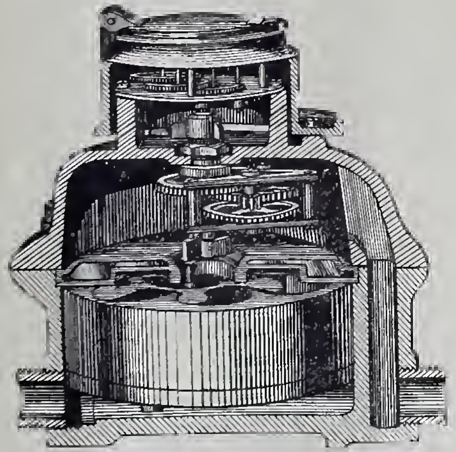
FIG 11.

AMERICAN WATER METERS.

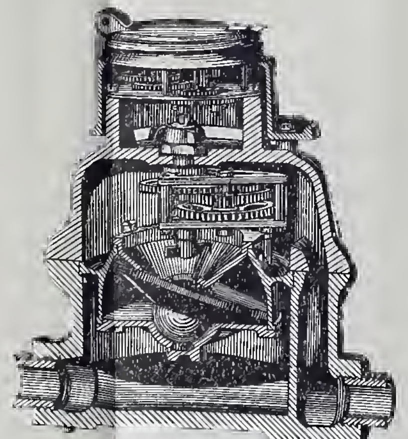
PLATE XLIX.



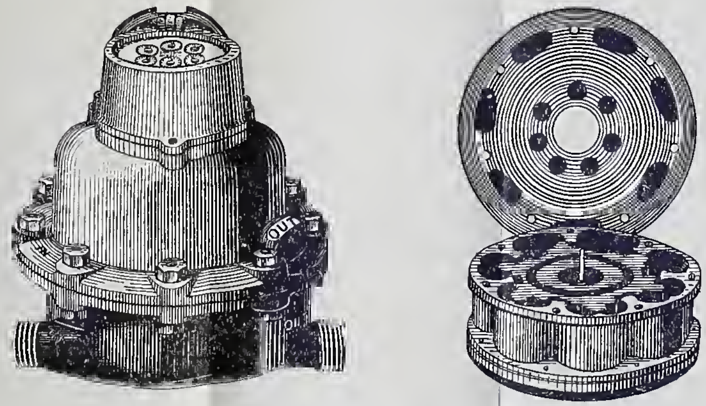
THOMSON'S BEE METER.



Hersey Water Meter.



Hersey Disc Meter.

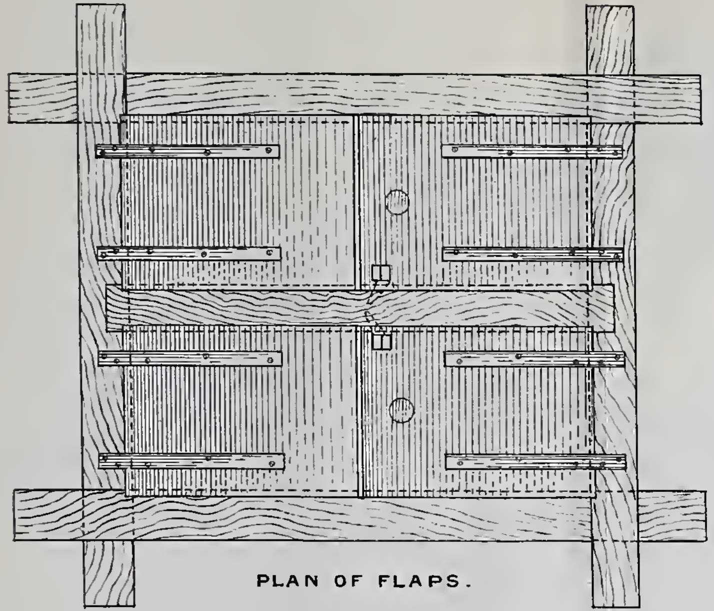


Crown Water Meter.

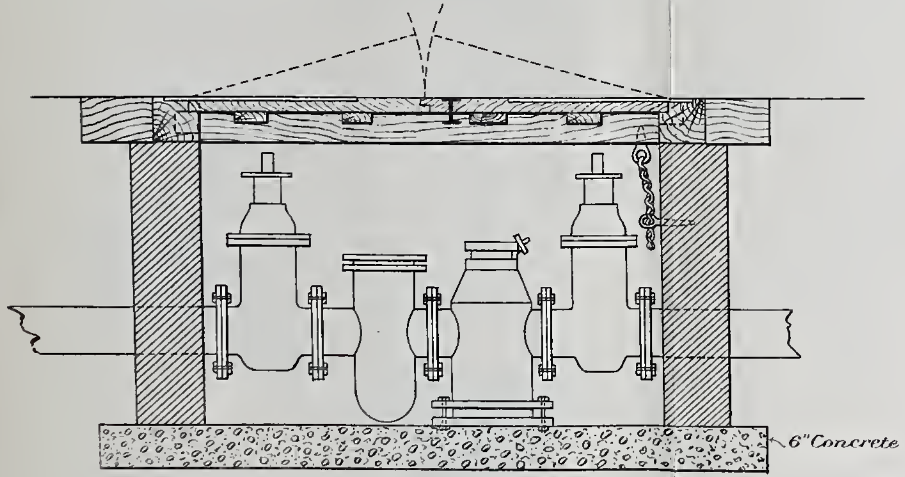
PLATE L.

ALDERSHOT, STANHOPE LINES.

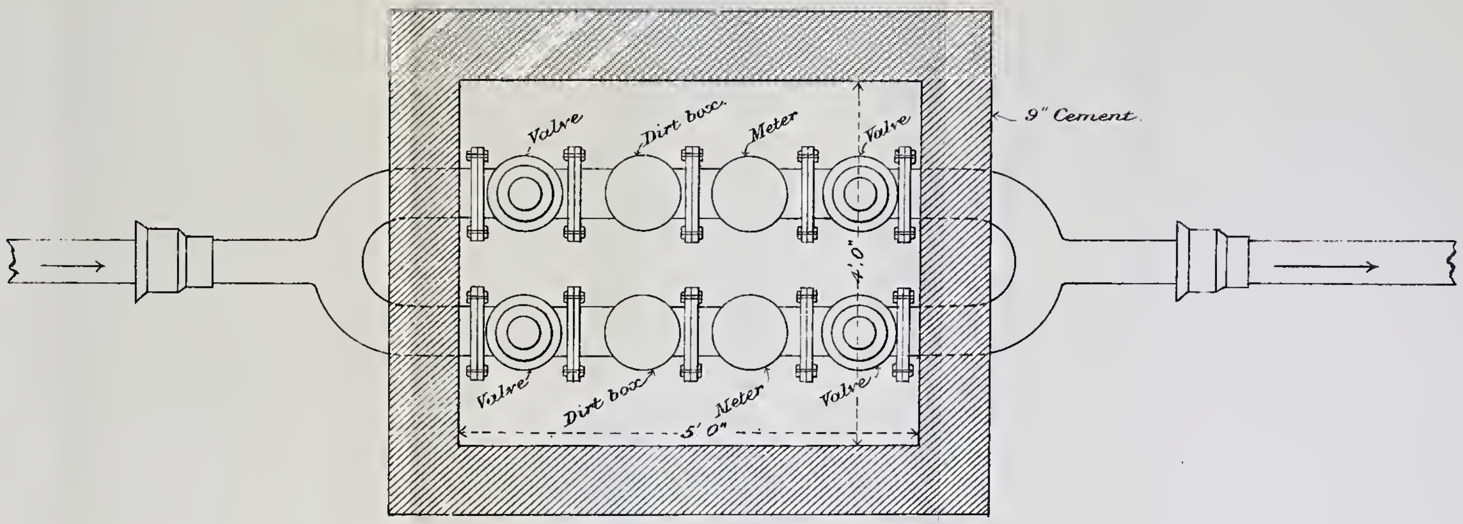
DETAIL OF WATER METER PIT.



PLAN OF FLAPS.



SECTION.



PLAN UNDER FLAPS.

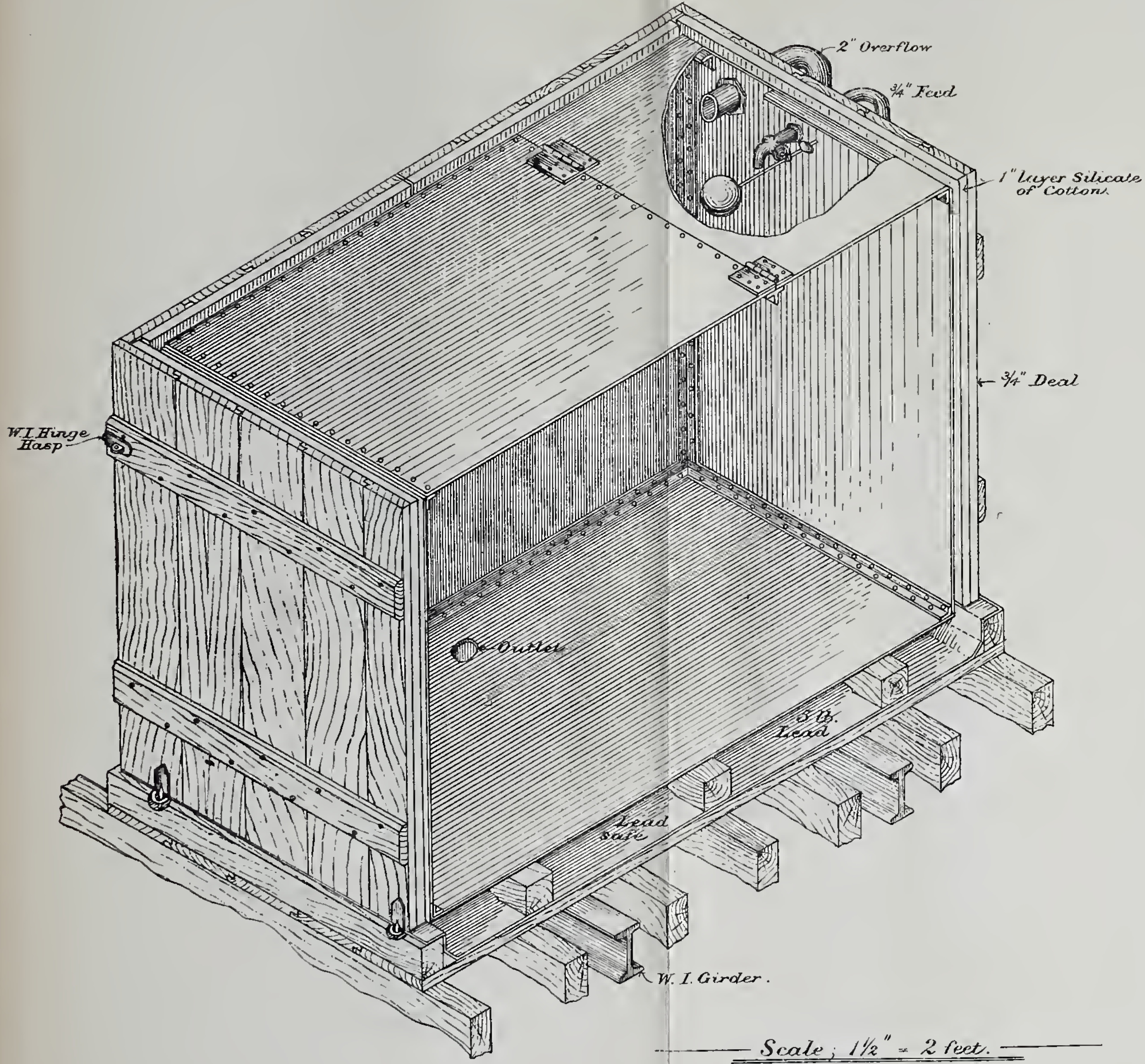
Specification.

6"x 6" Oak Curb rebated for flaps
& morticed & halved to receive bearer.
6"x 6" Oak bearer rebated to receive flaps.
2" Oak g^{d} & galv^{d} iron tongued flaps
with 4"x 2" Oak braces hung with
strong W.I. hinges let in flush.
2" Strong iron (galv^{d}) flush rings.
The bearer to be fastened with stout
galv^{d} iron eyes, chain & pin.

Half Inch Scale.

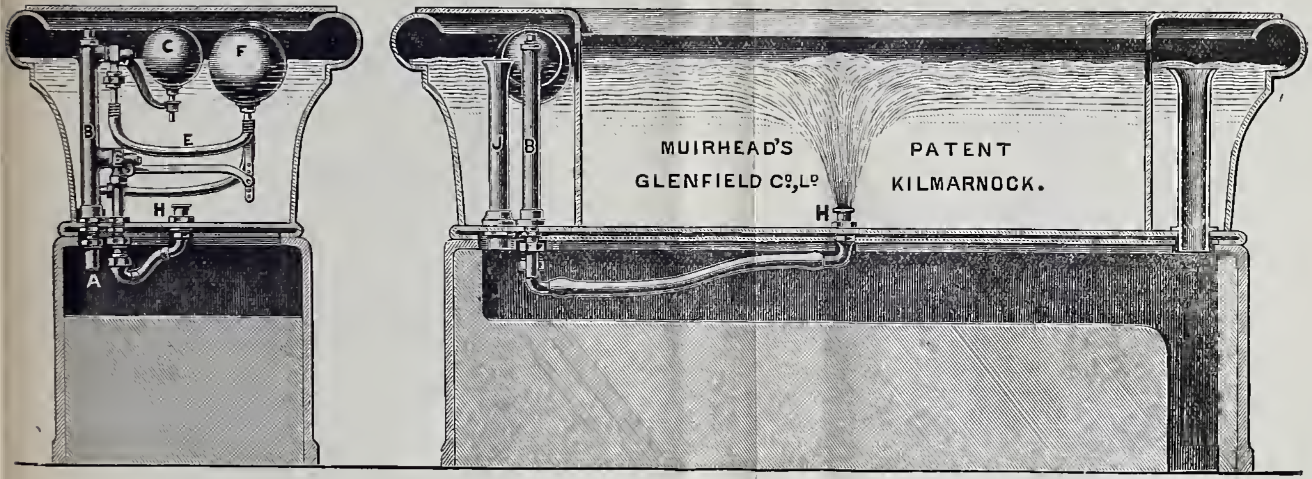
WATER SUPPLY.

Service tank for fixing in buildings, showing protection from frost.



Scale; 1½" = 2 feet.

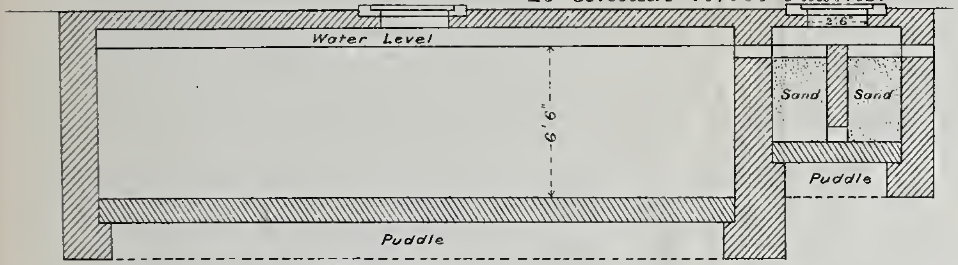
WATER TROUGH FOR HORSES.



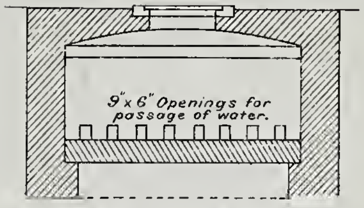
SOFT WATER TANK.

PLATE LIII.

To contain 10,000 Gallons.

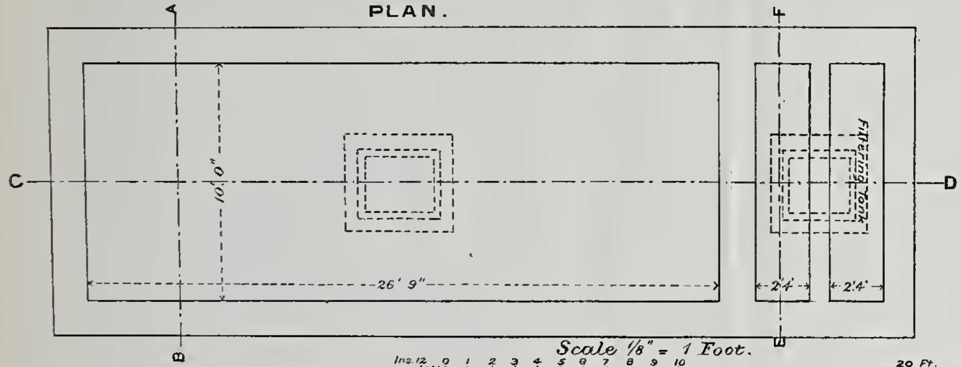


SECTION C-D.



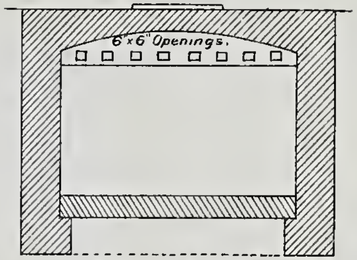
SECTION E-F.

PLAN.



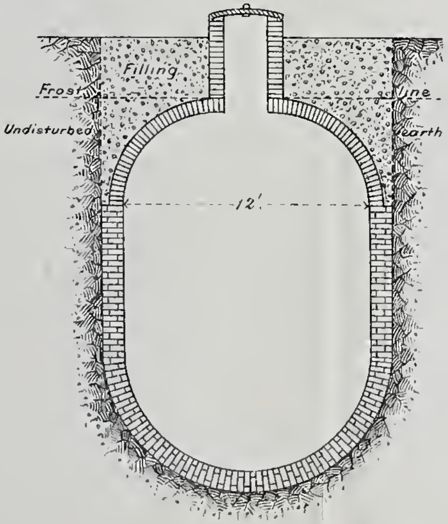
Scale 1/8" = 1 Foot.

Ins. 12 0 1 2 3 4 5 6 7 8 9 10 20 Ft.

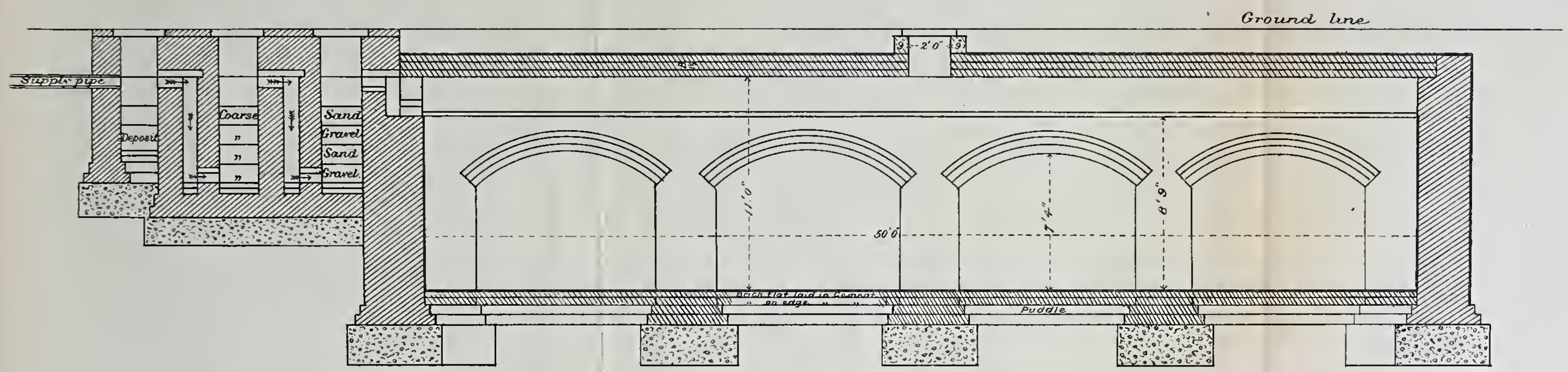


SECTION A-B.

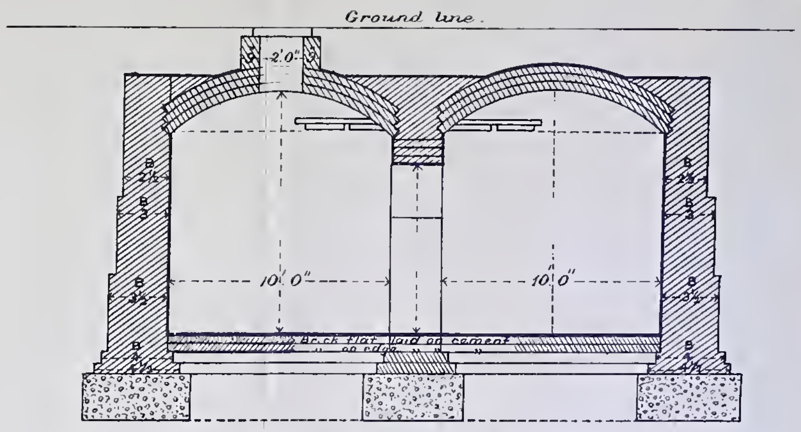
Cross Section of Underground Cistern of simple form.



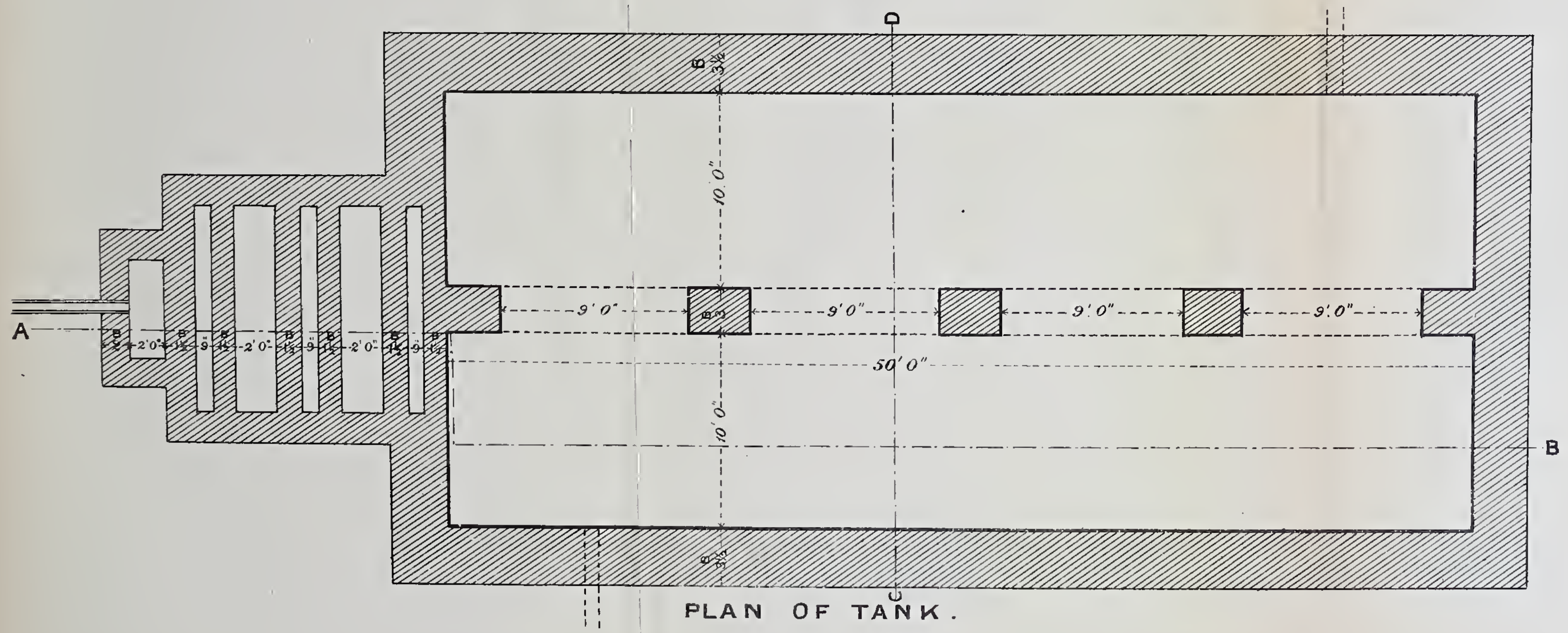
RAIN WATER TANK TO CONTAIN 58,000 GALS



SECTION ON LINE A-B



SECTION ON LINE C-D.

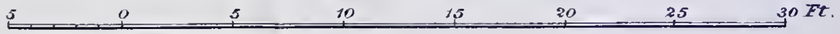


PLAN OF TANK.

Note:

The bottom, sides & ends of tank up to the level of springing of arch to be rendered in Cement.

Scale 8 Feet to an Inch



FIRE PROTECTION.
Hose Couplings.

PLATE LV.

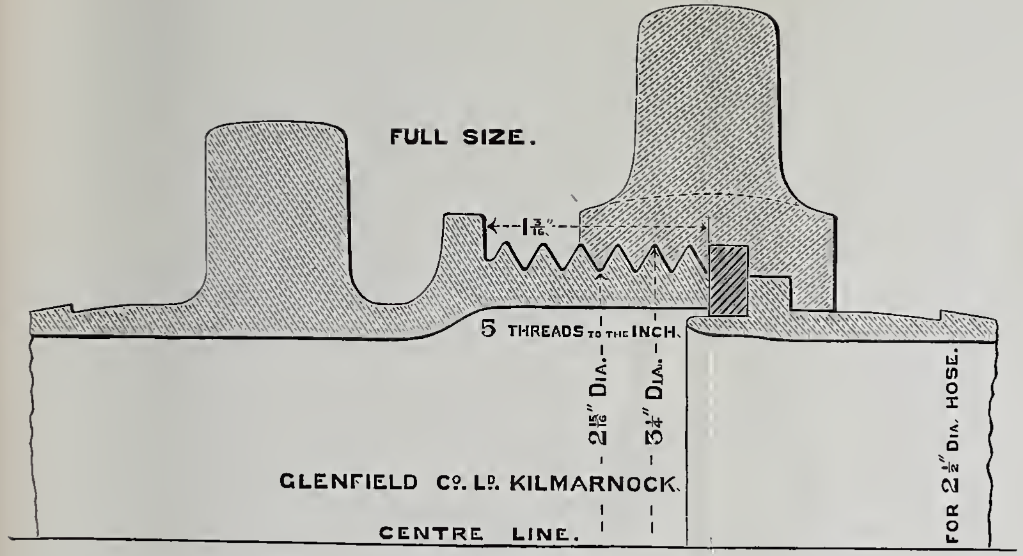


FIG. 1.—London Fire Brigade Coupling—Old Threads.

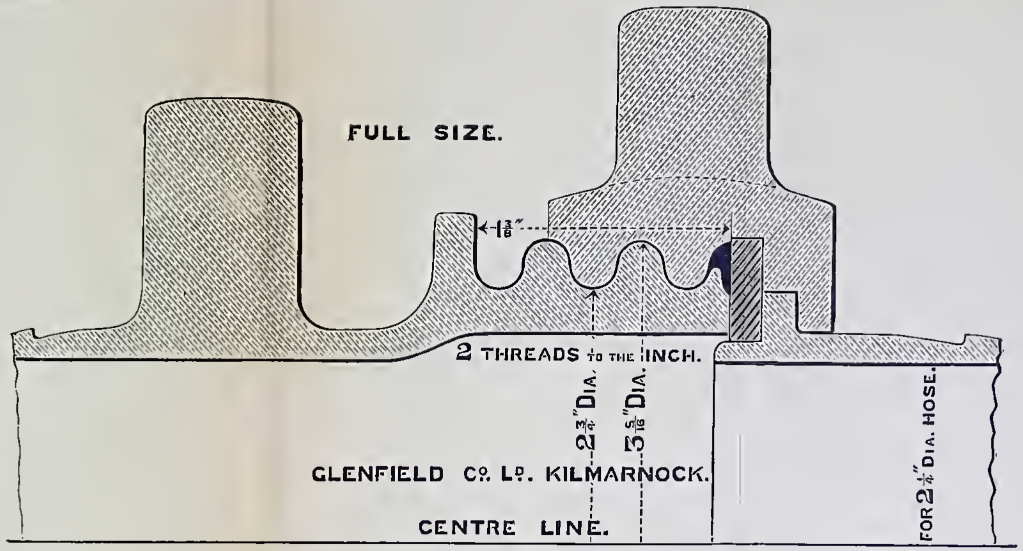


FIG. 2.—London Fire Brigade Coupling—New Threads.

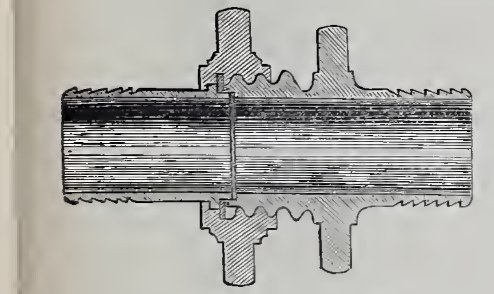


FIG. 3.—Section of New Coupling.

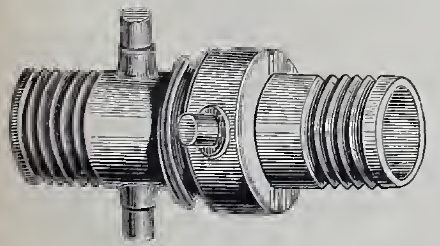


FIG. 4.—Fire Brigade New Pattern Coupling.

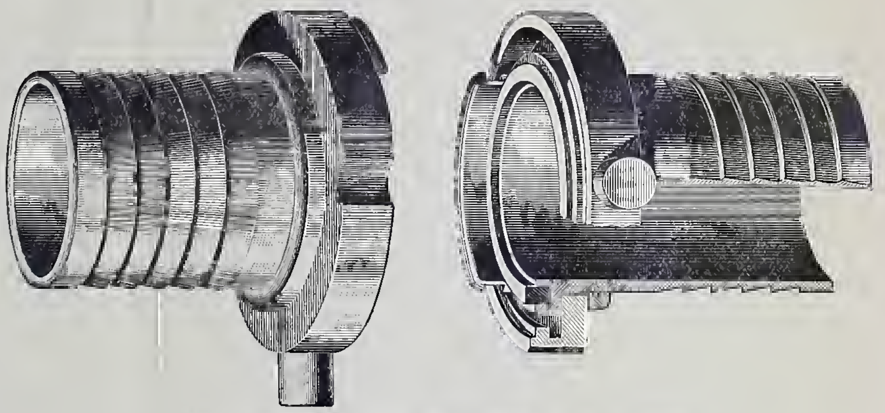


FIG. 5.—Instantaneous and Interchangeable Hose Coupling.

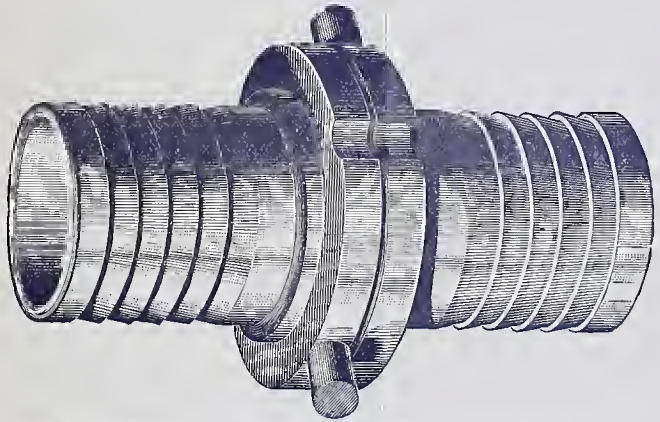


FIG. 6.—Instantaneous and Interchangeable Hose Coupling, Connected.

PLATE LVI.

ARRANGEMENTS
for Filling Water Skins, and Jars.

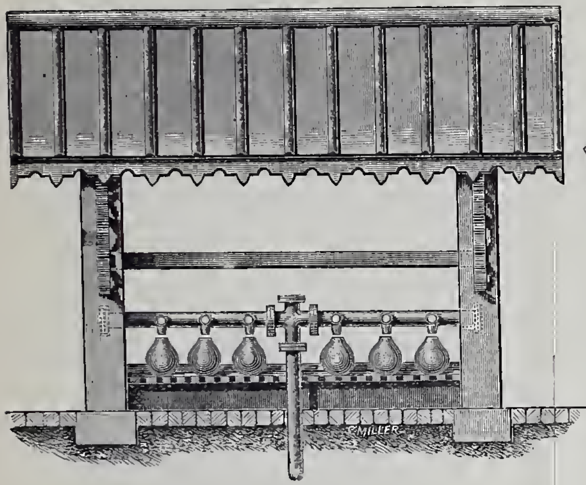


FIG. 1.

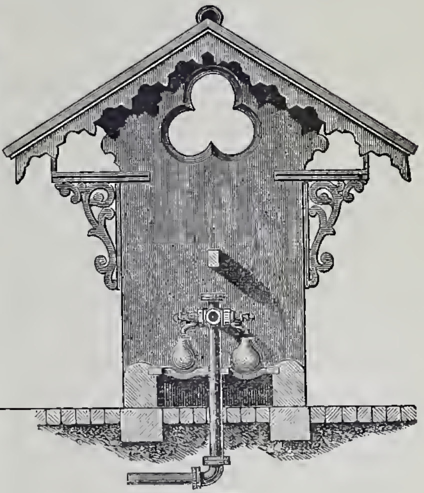


FIG. 2.

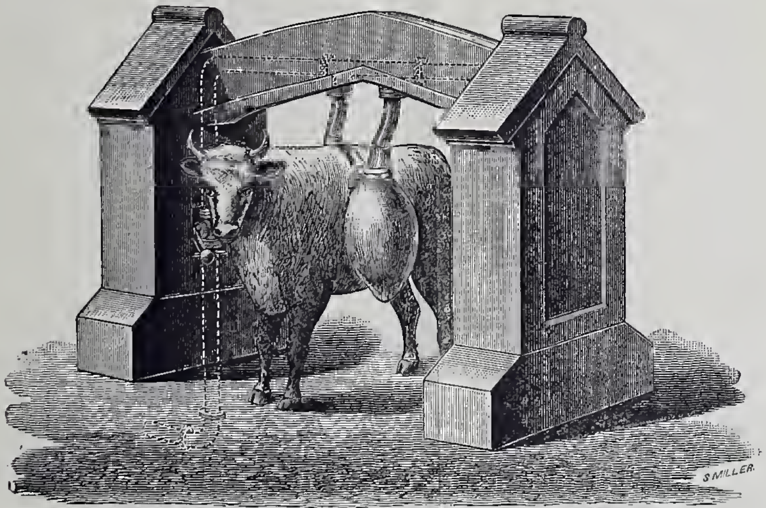
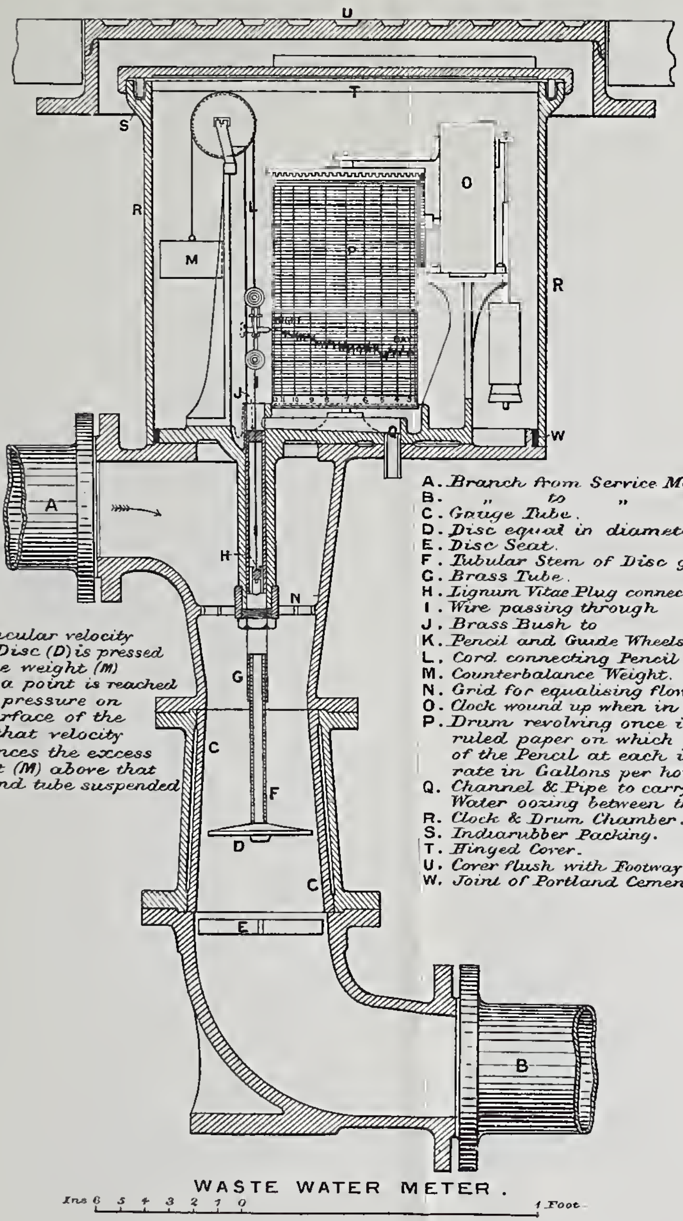


FIG. 3.

DEACON'S METER.

PLATE LVII.



A. Branch from Service Main.
B. " to " "
C. Gauge Tube.
D. Disc equal in diameter to top of Gauge Tube.
E. Disc Seat.
F. Tubular Stem of Disc guided by
G. Brass Tube.
H. Lignum Vitae Plug connecting Stem of Disc with
I. Wire passing through
J. Brass Bush to
K. Pencil and Guide Wheels.
L. Cord connecting Pencil with
M. Counterbalance Weight.
N. Grid for equalising flow of Water.
O. Clock wound up when in use once in seven days
P. Drum revolving once in 24 hours, carrying ruled paper on which is recorded the height of the Pencil at each instant & the corresponding rate in Gallons per hour.
Q. Channel & Pipe to carry away small quantity of Water oozing between the Wire and the Bush (J).
R. Clock & Drum Chamber.
S. Indiarubber Packing.
T. Hinged Cover.
U. Cover flush with Footway.
W. Joint of Portland Cement made after fixing Meter.

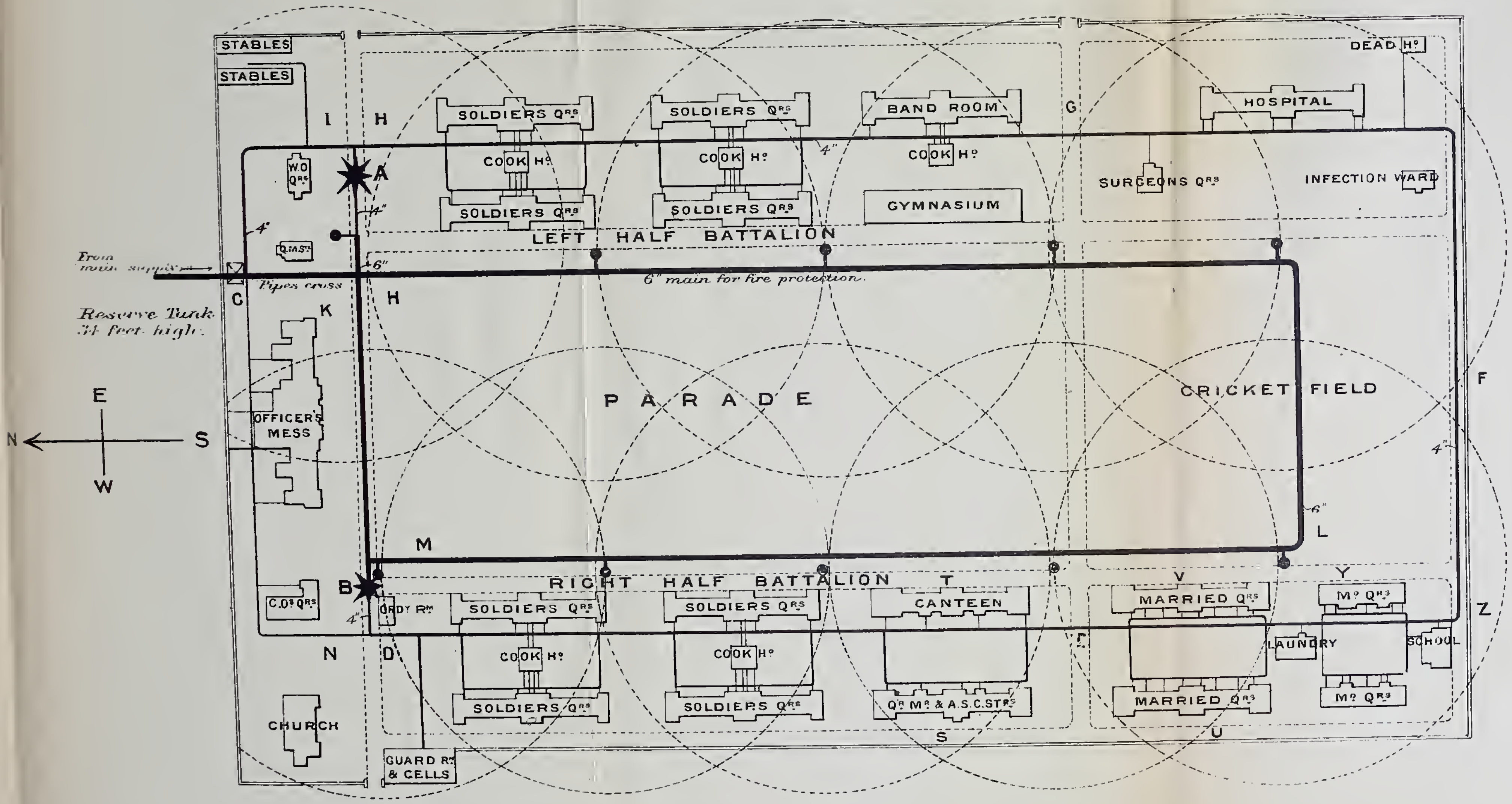
NOTE:

At each particular velocity of water the Disc (D) is pressed down and the weight (M) raised until a point is reached at which the pressure on the upper surface of the Disc due to that velocity exactly balances the excess of the weight (M) above that of the Disc and tube suspended in the water.

WASTE WATER METER.

TYPE OF BARRACKS FOR ONE BATTALION.

Shewing water mains.



Fire protection main 6" pipes ....

Hydrants ....

Supply mains 4" „ ....

Rider „ 3" „ ....

Service pipes 1" ....

In the event of fire, sentries close valves at "A" and "B" and the sergeant of the guard turns on the water from reserve tank, C.

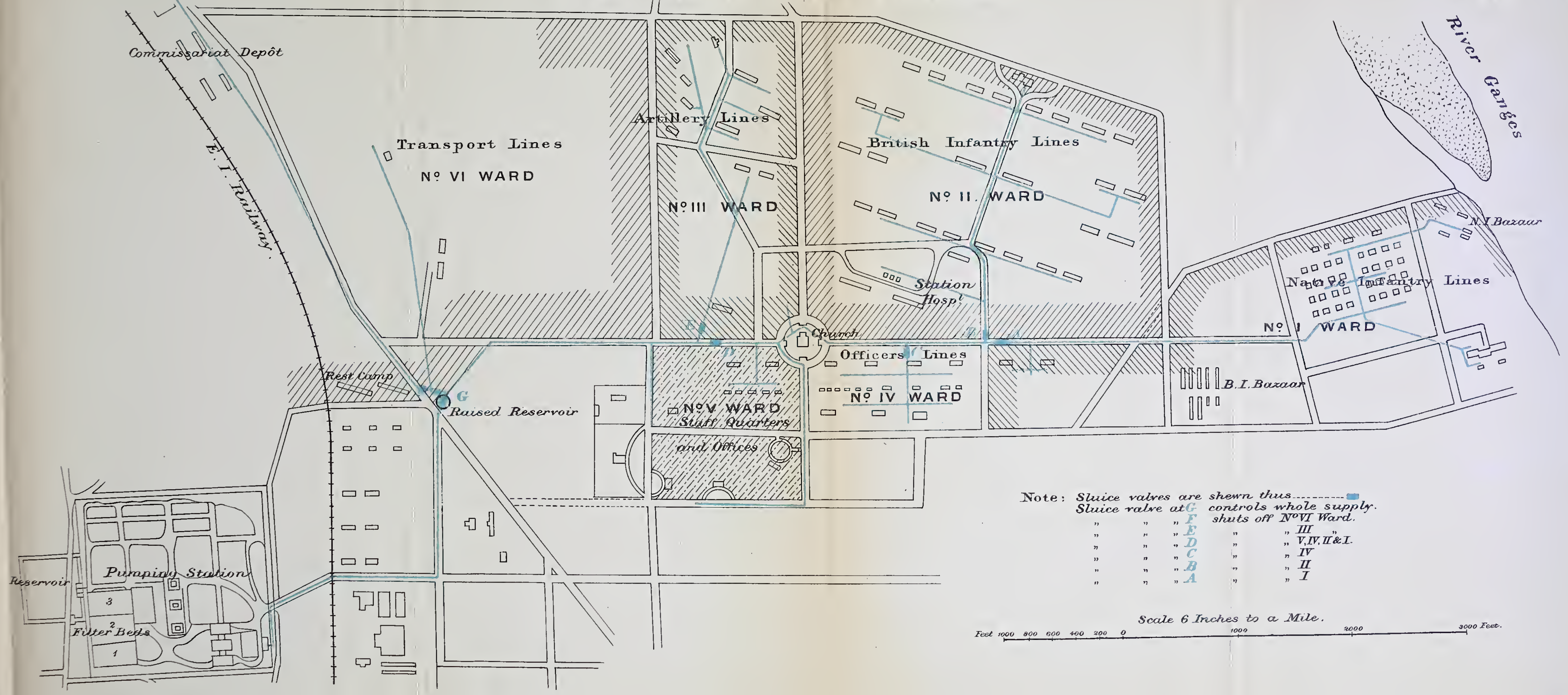
The supply is continuous and does not pass through reserve tank.

Scale of Feet.

100 0 100 200 300 400 500 600 700

PLAN OF DISTRIBUTION, ALLAHABAD.

PLATE LIX.

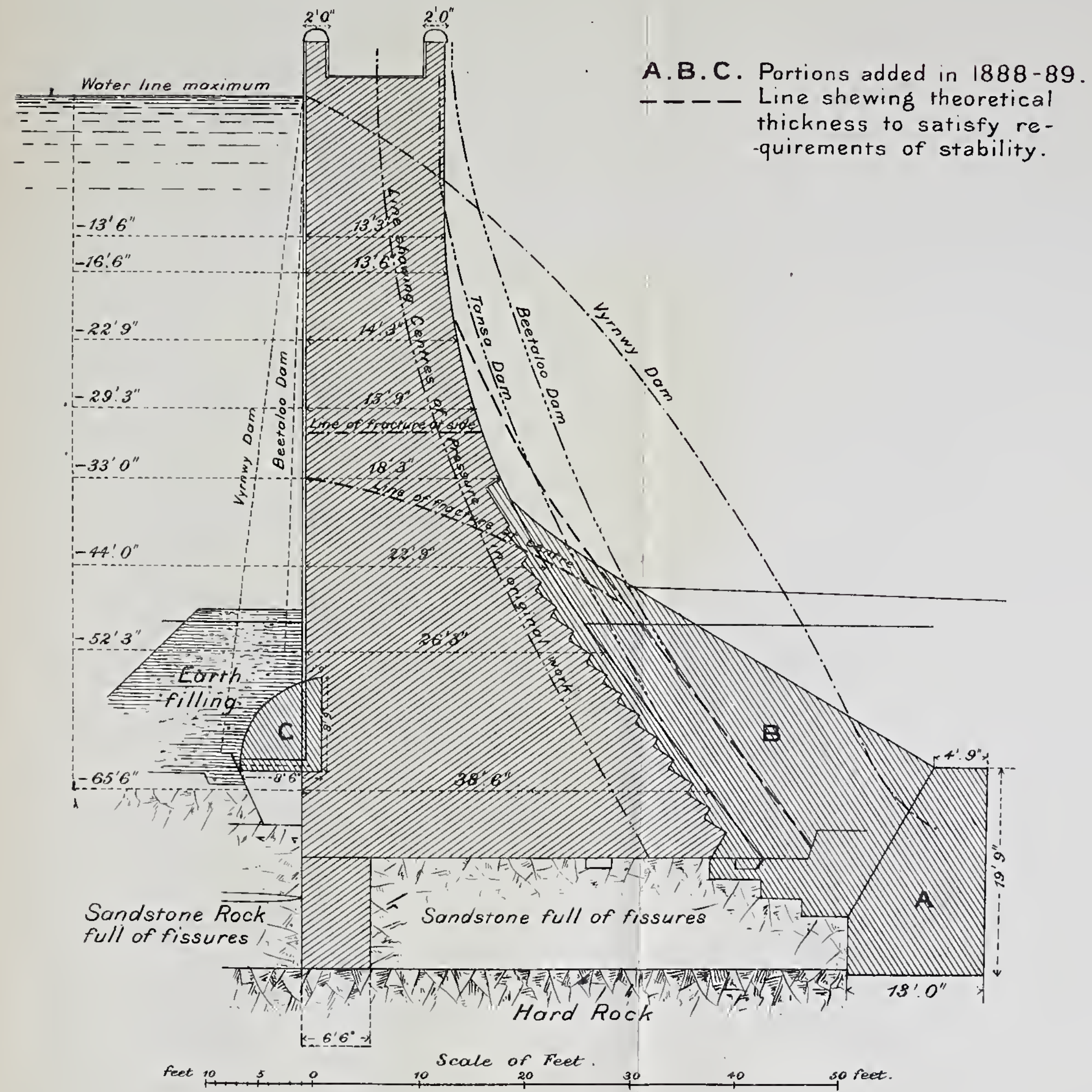


Note: Sluice valves are shewn thus.......... ▬
Sluice valve at G controls whole supply.
" " " F shuts off Nº VI Ward.
" " " E " " III "
" " " D " " V, IV, II & I.
" " " C " " IV
" " " B " " II
" " " A " " I

Scale 6 Inches to a Mile.

SECTION OF DAM AT BOUZEY, FRANCE. PLATE LX.

Failed 27th April, 1895.


A.B.C. Portions added in 1888-89.
Line shewing theoretical thickness to satisfy requirements of stability.
2'0"
2'0"
Water line maximum
-13'6"
-16'6"
-22'9"
-29'3"
-33'0"
-44'0"
-52'3"
-65'6"
13'3"
13'6"
14'3"
15'9"
Line of fracture at side
18'3"
Line of fracture at centre
22'9"
26'3"
38'6"
Line showing Centres of Pressure in original work
Tansa Dam.
Beetaloo Dam
Vyrnwy Dam
Vyrnwy Dam
Beetaloo Dam
Earth filling
C
B
A
8'6"
6'8"
4'9"
19'9"
13'0"
6'6"
Sandstone Rock full of fissures
Sandstone full of fissures
Hard Rock
Scale of Feet.
feet 10 5 0 10 20 30 40 50 feet.

6

26

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